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THE

WORCESTER SEWAGE

AND THE

BLACKSTONE RIVER.

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Commonwealth of Massachusetts.

Hon. R. R. Bishop, *President of the Senate.*

The undersigned, members of the State Board of Health, Lunacy, and Charity, in accordance with chapter 67 of the Resolves of 1881, herewith submit, for the consideration of the General Court, the special report of the Board on the subject-matter of the resolve, together with the reports, estimates, plans, and papers in their possession, which relate to the case.

THOMAS TALBOT.
R. T. DAVIS.
EZRA PARMENTER.
EDWARD HITCHCOCK.
CLARA T. LEONARD.
GEO. P. CARTER.
ALFRED HOSMER.
JOHN C. HOADLEY.

Boston, Feb. 4, 1882.

THE SEWAGE OF WORCESTER.

By chap. 67 of Resolves of 1881, it was made the duty of the Board to examine and consider the question of the disposition of the sewage of the city of Worcester, especially with a view to prevent the pollution of the Blackstone River and its tributaries, and to report its conclusions in print to the next Legislature, with recommendations as to a definite plan for the prevention of such pollution. The Board has attended to the duties thus imposed, and has examined that portion of the Blackstone River of which complaint had been made, and also the sewerage system of Worcester itself. Two hearings have taken place, at which all parties interested were notified to be present; and the Board, as already mentioned, has employed C. F. Folsom, M.D., of the National Board of Health, and J. P. Davis, C.E., of New York. These experts, together with the Health Officer of the Board, H. P. Walcott, M.D., have fully examined the subject of the purification of the Worcester sewage, and, after full consideration, have submitted to this Board the report which appears in the Sanitary Appendix.

The authorities of the city of Worcester and the town of Millbury were invited to employ, at their own expense, such persons as might seem to them best qualified to examine, in their behalf, the matters referred to, and to report to this Board.

The city of Worcester failed to comply with this request. The town of Millbury secured the services of Col. G. E. Waring, jun., of Newport, R.I., whose report has been presented, and is printed in the Sanitary Appendix.

The plan proposed by Col. Waring, in this very interesting and able report, is, in the opinion of this Board, open to the following objections: —

OBJECTIONS TO COL. WARING'S PLAN.

First, That the scheme for dividing the flow of the sewage between two narrow channels, one at each side, with a wider channel between them for surface drainage, — the whole to form a single channel whenever, in times of freshet, the surface drainage may rise sufficiently to overflow the partition walls, — is not satisfactory for the following reasons: —

1. The very important portion of the sewer beneath the road-bed of the Boston and Albany Railroad is, in its present form, barely capacious enough to receive and carry off the storm-flow of Mill Brook. The device recommended would, however it were carried out, impair seriously this capacity, while the cost will be very considerable, — little, if any, less than that of a separate sewer for the sewage proper.

2. Dividing the sewage between two channels must greatly diminish the scouring power of the current, by reducing the flow in each of the open ditches so formed, — ditches open, that is, to the main sewer.

3. The large surface that would become coated with sewer-slime, and be exposed to the air of the main sewer, would also be an objection.

4. The great capacity of the main sewer would still constitute it, as now, a vast receptacle for sewer-gases.

Second, The plan of allowing the sewage to flow off upon low lands, advantageous as it appears, and advantageous as it would be, to avoid pumping, seems to us highly objectionable.

1. It cannot be done except upon swampy land, unable to receive more water without flooding. If ditched, as proposed, the ditches would probably fill with water drawn from the soil. Vegetation could dispose of little more water than it now does, and could do little towards absorbing any of the sewage.

2. There would be no aëration except upon the surface; no alternation of air and water in the same interstitial spaces in the ground; no oxidation of organic matters contained in the sewage.

On the other hand, the plan presented by the expert commission seems to meet the objections above enumerated, with well-considered remedies: —

THE WORCESTER SEWAGE. — CONCLUSION.

I. Once pumped to a sufficient height, the sewage will flow upon a tract of land of sufficient extent, at such a height above the natural drainage as to give a body of earth, which, when properly drained and prepared, will admit of alternate flow of air and water; of fresh air through well-moistened earth, from which the sewage has recently drained off; of newly supplied sewage through freshly aërated soil, on every side of every pebble, of every grain of sand, of every lump of marl or loam, — thus becoming a portion of the vast lung-surface by which the purification of the sewage is to be brought about through the action of the free oxygen of the air on the oxidizable matter in the sewage.

II. The proposed sewage-pipe must perform perfectly all that the three-channel plan of Col. Waring would, as it seems to us, do less perfectly.

Col. Waring's plan — though it does not, in our opinion, offer so satisfactory a system of irrigation as that proposed by us — brings to this method of sewage-disposal the approval of a very eminent authority in matters of this sort, especially in the light of his own recent critical examination of the most approved methods of drainage both in England and on the Continent. As no plan for the purification of so large an amount of sewage has yet been put in practice in this country, all methods proposed are, to a certain extent, experimental. Still, after mature deliberation, the Board accepts with great confidence the conclusions stated in the report of its experts; being convinced that the system of "intermittent downward filtration," supplemented, if necessary, by broad irrigation, is best adapted to the existing condition of things. And we therefore recommend the system of intermittent downward filtration, submitted in the report of the experts appointed by this Board, as, in the judgment of the Board, the best method of disposing of the sewage of the city of Worcester.

* The extremes in Boston from 1849 to 1875 were 40.3 and 67.7 inches.

THE WORCESTER SEWAGE AND THE BLACKSTONE RIVER.

I. — REPORT OF THE BOARD'S COMMITTEE OF EXPERTS.

BOSTON, NOV. 17, 1881.

To the State Board of Health, Lunacy, and Charity.

In conformity to the vote of the Board, July 23, 1881, —

That Dr. C. F. Folsom, Joseph P. Davis, Civil Engineer, of New York, and Dr. H. P. Walcott, Health Officer of the Board, be requested to examine and consider the question of the disposition of the sewage of the city of Worcester, especially with a view to prevent the pollution of the Blackstone River and its tributaries, and report to this committee, —

We have the honor to submit the following report: —

The population of Worcester was, by census, 22,286 in 1855, 24,960 in 1860, 30,055 in 1865, 41,105 in 1870, 49,317 in 1875, and 58,291 in 1880. These figures show an average increase for each five years of a little over 20 per cent, and warn us, that, in designing works for the disposal of the sewage of the city, ample provision should be made for its future growth.

The populated area of the city is now 2,967 acres, of which 1,300 are already sewered; the total length of the sewers, exclusive of the Mill Brook Conduit, being 36 miles.

The average rainfall is 48 inches * annually. The mean temperature (F.) at two points in the State for ten years is as follows, the extremes being from a little over 100°+ to several degrees below zero: —

MONTHS.	CAMBRIDGE Ten Years, 1868-77.	AMHERST. Ten Years, 1868-77.	MONTHS.	CAMBRIDGE Ten Years, 1868-77.	AMHERST. Ten Years, 1868-77.
January	25.3	24.2	August	69.6	69.1
February	25.2	24.5	September	60.9	60.0
March	31.4	31.4	October	49 8	48.4
April	43.2	44.3	November	37.4	37 3
May	55.6	55.0	December	27.5	26.2
June	66.6	67.3			
July	72.3	71.1	Average	47.1	46.6

* The extremes in Boston from 1849 to 1875 were 40.3 and 67.7 inches.

THE BLACKSTONE RIVER AND THE WORCESTER SEWAGE.

The ground freezes from three to five months in the year to a depth varying from one foot to five feet; the snow covers the ground from a few weeks to three or four months, from one foot to three feet deep.

The eastern and most thickly built portion of the city is drained by a considerable stream, called Mill Brook, which, flowing almost due south, empties into the Blackstone River a little above the village of Quinsigamond. This brook receives, along its course, nearly the whole of the sewage of Worcester, brought to it by 44 different sewers. Its drainage area above Lincoln Square is about 8 square miles; above Cambridge Street it has a drainage area of about 12½ square miles. Its average daily dry-weather flow at Cambridge Street, exclusive of sewage, for four months of the year, may be stated at about 3,500,000 gallons, and its minimum daily flow for a single month at 750,000 gallons.

The average gauged flow at Lincoln Square for 79 days in the summer of 1871 was 4,198,000 gallons daily. The flow in times of great freshets may reach the enormous quantity of 1,000,000,000 gallons in 24 hours; but the greatest noted discharge (at Pond Street) was at the rate of 110,000,000 gallons.

The average daily flow for the year is about 13,000,000 gallons.

From the above statement it is evident that, to make practicable any scheme for utilizing or purifying the sewage, it must be intercepted before it reaches the brook.

No extended or reliable gaugings have been made of the dry-weather flow of the sewers. The sewer which enters the brook at Cambridge Street drains what are known as the Island and Piedmont Districts, having a total area of about 670 acres. Mr. Phinehas Ball, former city engineer, in a report made to C. D. Morse, Esq., in this year, estimates the dry-weather flow at about 800,000 gallons daily; and in his opinion, when the Island District is more completely sewered, it will be increased to 1,000,000 gallons. Rough float-gaugings, taken in 1875 from Aug. 26 to Sept. 2, showed the average daily flow of that period to be 1,300,000. The maximum daily flow for that period was 1,463,256 gallons;

and the minimum, 1,135,872 gallons. For the purposes of this report, it is assumed that the dry-weather flow of the sewers of the city is at present 3,000,000 gallons per day, 2,000,000 gallons of which empty into Mill Brook above Cambridge Street, and 1,000,000 gallons at Cambridge Street. Twenty-eight hundred * houses are connected with the present sewers; 4,000 * houses are not connected. There are 26 woollen and cotton mills, beside a few iron-works, saw-mills, grist-mills, a tannery with shambles on the river and its tributaries above the sewer outlet. About 50 gallons of the water-supply are used per individual.

So many samples of the sewage of Worcester were examined by the State Board of Health in 1872, that it is not necessary to repeat the analyses.

Of 27 samples collected from three sewers on eleven different days at six A.M., nine and twelve P.M., the average proportions were, in parts per 100,000, solid residue, 15.29; ammonia, 0.745; albuminoid ammonia, 0.144; chlorine, 3.1. Of 27 samples collected at nine A.M., twelve M., and six P.M., the average was, of solid residue, 25.35; ammonia, 1.876; albuminoid ammonia, 0.316; chlorine, 4.17. The mean of 12 of the first set of samples showed phosphoric acid, 0.1940; and of 12 of the second set, phosphoric acid, 0.6564.

The averages from 50 English cities and towns were, in parts per 100,000, solid residue, 72.2; ammonia, 6.703; chlorine, 10.66. We have, therefore, 3,000,000 gallons of sewage to deal with daily, which the chemical analyses just quoted show to be about twice as dilute as the sewage of English towns, mixed with a brook, whose daily flow ranges from 1,000,000 to 40,000,000 gallons, not including extremes in a rapidly growing city.

Chemical analyses of the water supplied to the river before and after pollution by the sewage of Worcester, made in 1875, showed the following results in parts per 100,000: —

* Approximately.

SPECIAL SANITARY APPENDIX.

	Ammonia.	Alb. Ammonia.	Solid Residue.	Chlorine.
City Reservoir	0.0107	0.0213	4 20	0.18
Mill Brook	0.9600	0.1109	23.44	3.80
Blackstone River, at the sash factory	0.0992	0.0307	8.04	0.92
Blackstone River, below Blackstone Mills	0.0099	0.0139	4.80	0.38

Mill Brook, with its accumulated sewage, empties into the Blackstone River at a point about three miles above the more thickly populated portion (the village) of the town of Millbury. The river flows parallel to and alongside of the main road connecting Millbury with Worcester, and at a point about midway is ponded by a dam. Here a considerable portion of the solids held in suspension are deposited, and a nuisance is created. In the town of Millbury are a number of dams, at each one of which some further deposition occurs; and along the whole course of the stream for some miles below Worcester putrefaction of the organic constituents of the sewage takes place (most rapidly in the summer months), and, as a consequence, offensive gases are liberated, which are largely the cause of complaint of this method of disposing of the sewage.

The deposits undoubtedly stimulate and increase the growth of aquatic plants, and are thus, as well as by their own bulk, hastening the process of filling up the ponds. This, too, is a cause of complaint by the Millbury mill-owners. It is a belief of the people dwelling on and near the banks of the stream, that a perceptible injurious effect upon the general health has been produced, and this belief is shared in, to some extent, by the resident physicians.

That the stream at times is very offensive is quite evident, and that this, in connection with the gradual filling up of the ponds, will soon depreciate the value of property in its vicinity, unless some other than the present method of disposing of the sewage of Worcester is adopted, is beyond question. It should be stated, however, that a not inconsiderable portion of the pollution of the river below Millbury is

contributed by the mills of that town situated on the main stream, and on Singletary Brook.

The stream four miles below the sewer-outlet is unmistakably polluted; twenty-five miles down, the impurity is all but lost to chemical tests. At Millbury the water is unfit for the nicer manufacturing processes, and for boilers, and at times is decidedly offensive.

During the summer of 1881 the following analyses of water, taken in quite dry weather, made under the direction of Professor E. S. Wood, are compared with others in 1872 and 1875 by Professor W. Ripley Nichols in the State Board of Health Report: —

Examination of Blackstone River.

(Parts per 100,000.)

	Date.	Unfiltered.			Residue.			
		Ammonia.	Alb. Ammonia.	Chlorine.	Fixed	Volatile.	Total.	Hardness.
	1872.							
Average of 11 samples, Mill Brook, at Cambridge Street	Oct. –	0.3430	0 2290	2.74	–	–	14.90	–
Average of 12 samples above sewers, Mill Brook	–	0.1970	0.1800	1.62	–	–	15.71	–
	1875.							
Mill Brook, near river	July –	0.9600	0.1109	3 80	–	–	23.44	–
Blackstone River, near sash factory	–	0.0992	0.0307	0 92	–	–	8 04	–
River, near Blackstone Mills	–	0.0099	0.0139	0 38	–	–	4.80	–
River, below dam at Blackstone		0.0157	0.0163	0.36	–	–	4.60	–
	1881.							
Blackstone River, bridge below Perry's Mills, Quinsigamond	Aug. 30	0.9360	0.0858	2.90	5.00	7 50	12.50	3°
Blackstone River, bridge below Perry's Mills, Quinsigamond	Sept. 6	0.3360	0.0882	3.10	8.40	4.00	12.40	3°
Blackstone River, bridge below Perry's Mills, Quinsigamond	11	0.0094	0 1606	3.30	13.30	11.00	24.30	6°
Above Burling Mills	Aug. 30	0 0746	0 0470	2.10	4.00	5 50	9.50	3°
Above Burling Mills	Sept. 6	0.1814	0.1168	3 20	9.50	0.80	10.30	3°
Morse's Mill-pond	Aug. 30	0.0720	0.0690	2 80	8.80	0.90	9.70	3½°
Gowan's Bridge	30	1.1880	0.0334	2.20	9.00	1.90	10.90	2½°

EXAMINATION OF BLACKSTONE RIVER.

Gowan's Bridge	Sept.	6	0.0013	0 2906	4.60	10.00	3 90	13.90	6°
Above Cordis Mills	Aug.	30	1.3230	0.1364	3 00	8.00	4.60	12.60	4°
Blackstone River, above Worcester sewage . .	Sept.	6	0.0315	0.0264	1.10	5 50	2 10	7.60	1°
Mill Brook, with sewage at Cambridge Street .			0.0880	0.3910	7 30	22.10	12.00	34.10	8°
Mill Brook, with sewage at Cambridge Street .	Oct.	2	0.1440	0 0486	1 90	8.30	3.70	12.00	2½°
Singletary Brook		2	0 0112	0.0458	0.60	2 50	5.80	8.30	1½°
Blackstone River, below Singletary Brook . .		2	0.1546	0 0332	1 80	7 60	3.70	11.30	2½°
Blackstone River, above Singletary Brook . .		2	0 0866	0.1662	2.00	10.80	5.80	16.60	3°
Below Boston and Albany Railroad, and above Fox Village		27	0.5060	0 1100	5.20	21.90	5 10	27.00	9°
Junction of Mill Brook and Piedmont sewer .		27	0.6400	0 2400	8.30	26 30	12.50	38.80	8°
Lynde Brook, above South Worcester Wire Mill and below Worcester Carpet Company . .		27	0.0370	0.0210	0 80	3.40	0 90	4.30	1°
Mouth of sewer at Quinsigamond Village . .		27	0.9100	0.1700	9.30	30 40	7.00	37.40	8°
Above Burling Mills		27	0 3070	0.0370	2.90	9.20	2 20	11.40	3°
At Morse's Bridge, in front of factory . .		27	0.0470	0.1410	2 90	8.40	3.70	12.50	3½°

SPECIAL SANITARY APPENDIX.

Comparing the results from the several examinations in 1881 with these of the State Board of Health in 1872, it is clear that the pollution of the stream has increased since that time. As compared with the chemical examinations made by the Board in 1875, there is also an increase, although much less marked. The sewage deposits have been to a certain extent swept away by freshets from time to time, and have not been augmented, except possibly above the dam of the sash factory in Millbury, so considerably as to be of themselves the nuisance that might have been expected.

Considering the extreme heat and cold of the climate, the heavy rainfall, and the great dilution of the sewage, the difficulties in the way of a satisfactory disposal of the sewage of Worcester are far beyond those of any other town where the question has already been met: so that any scheme that may be proposed may be said to be experimental to a certain extent; and to be successful, and not create a greater nuisance than it abolishes, it must be costly in the original outlay, and involve also a considerable yearly expense.

Various methods of preventing the excessive pollution of streams have been adopted or experimented upon in England. They may be classified as follows: —

1. Simple subsidence in tanks.
2. Chemical treatment or precipitation in tanks.
3. Filtration through artificial filters.
4. Intermittent filtration through natural soil.
5. Broad irrigation.

The first and third are very generally abandoned. They simply remove floating solids, leaving all the putrescible solubles to beget a nuisance when putrefaction begins.

The second method produces an effluent which may be allowed to enter most streams that are not afterwards used as a source of water-supply, and is one that a number of towns are constrained to adopt for want of land proper for filtration or irrigation. It removes all the solids, and a small percentage of the soluble elements; and the chemicals used in the various processes tend to fix the remaining putrescible elements in various degrees. Over sixty different precipitation processes have been proposed.

The cheapest one is that known as the lime process, in which about one ton of lime is added to each million of gallons of sewage of the English standard of dilution.

The sewage is then allowed to flow very slowly through a series of carefully constructed tanks in which the floating solid matter, and that produced by the chemical action of the lime, are deposited, forming what is technically termed "sewage sludge." When the sludge has accumulated to a few inches in depth, the supernatant liquid is carefully drawn off, and allowed to flow over irrigation fields or into the neighboring stream. The sludge, consisting in this state of 90 per cent of water, is removed (usually by pumping), and is finally disposed of in some way. After being exposed to the air for a year in the climate of England, it still contains 70 per cent of water.

It may be allowed to accumulate on the land, or it may be dug into the soil to serve as a manure. It is usually given away, or sold (if possible) when partially dried. It is sometimes artificially dried at great expense, when its bulk is so reduced that it becomes a salable manure.

In some towns in England the farmers pay a shilling or two a ton for the air-dried sludge at the leisure time of the year; in others they will not cart it away when given to them.

There are many other chemicals than lime in use in the precipitation processes, many of which produce a slightly better effluent, and a more valuable sediment (if a comparison of the value of materials that are practically worthless may be made), and much less of it. In these respects they are to be preferred; but under most circumstances they are more costly. Where the sludge can be allowed to accumulate without causing a nuisance, the lime process will usually be adopted, although the effluent still contains a considerably greater portion of the putrescible element than in other processes.

Where possible, this effluent should in all precipitation processes be passed through the soil before entering the stream.

For the treatment of the dry-weather sewage of Worcester,

we may assume, in the absence of actual experiments, that between two and three tons of lime per day would be required; that from forty to sixty tons of wet sludge, with 90 per cent of water in it, will be produced daily; and that the cost, exclusive of interest on cost of works, would be from $10,000 to $15,000 per year. This is under the assumption that the sludge is allowed to accumulate, or is given away. It is not probable that it could be sold, unless first treated by some process, which would be at a loss.

To create no nuisance in hot weather by any precipitating process is simply impossible; but the stench need not at any time be a serious matter to the town if the works are a mile or two distant. It can safely be said that nothing but a large expenditure originally, extreme care, and a liberal appropriation each year will prevent a nuisance from being established, if this method be adopted. The resulting "cleansed" water, not having removed from it the soluble filth, decomposes, and creates offensive smells, unless still further purified by running it over land in irrigation. The whole process is quite incomplete, so far as purification of streams is concerned; and on account of its much greater expense than that of irrigation is justifiable only where something must be done, and enough land cannot be got for irrigation.

The fourth method, or that of intermittent filtration, is usually employed, when at all, as an auxiliary to broad irrigation.

It consists, *per se*, in passing intermittently as large volumes of sewage through carefully prepared land as can be made to pass and produce a satisfactory effluent. In most cases, where any considerable area is acquired for the purpose, the net loss is diminished by cultivating crops, as that cannot be done where the greatest amount of sewage that can be filtered is used.

The land, no matter how porous naturally it may be, is thoroughly underdrained; and to get the best results the surface must be shaped to level terraces. If crops are to be grown, it should be further prepared in ridges and furrows, — the former for the growth of the crops, the latter for the distribution of the sewage to their roots.

Intermittent downward filtration has been adopted in Merthyr Tydvil in Wales; but it has been there abandoned in favor of ordinary surface irrigation and modified intermittent downward filtration, as no crops of value could be raised where the amount of sewage per acre (100,000 gallons daily) is so great. It is very seldom that land can be found porous enough for that method of disposing of sewage, there being only one town (Kendal in England) where any considerable quantity of sewage (nearly a million gallons daily on five acres) is now treated to the full extent in that way. Intermittent downward filtration differs from ordinary sewage irrigation simply in the extremely porous character of the soil selected, in the great amount of sewage used per acre, and in the abandonment of any attempt to raise crops of any real value; although, by taking more land than was at first designed by Denton, the amount of sewage used to each acre may be so moderate in amount that excellent crops can be raised: and this has actually been the practice in several towns that have recently adopted intermittent downward filtration in England, of which Abingdon is perhaps the best illustration.

The theory of the process is well described in the report of the English Rivers Pollution Commission, that such a filter is not a mere mechanical contrivance: it is a machine for oxidizing, and thus altogether transforming, as well as for merely separating, the filth of dirty water. A field of porous soil irrigated intermittently virtually performs an act of respiration, copying, on an enormous scale, the lung-action of a breathing animal; for it is alternately receiving and expiring air, and thus dealing as an oxidizing agent with the filthy fluid which is trickling through it. A sufficient extent and depth of porous soil having periodical intervals of rest, during which the soil drains itself, and becomes refilled with air, certainly must be the best possible strainer, oxidizer, and filterer of water containing nauseous organic impurities, both suspended and dissolved.

At Quinsigamond there is an area of land fairly well suited for modified intermittent filtration of sufficient extent to dispose of all the sewage of Worcester, as will be seen by refer-

ence to the accompanying map. The results of this method, so far as the quality of the effluent is concerned, will be quite satisfactory; and, without doubt, the yearly loss will be very much less than with the precipitation process. If intelligently managed, the crops should partly repay the cost of labor and pumping, and possibly also in good years the whole of it, inasmuch as we propose distributing only 40,000 gallons of sewage to the acre, or one-fifth as much as is the practice in Kendal, but about twelve times as much as could be used in ordinary surface irrigation.

The fifth method, or that of broad irrigation, is used with more or less modification, in varying degrees of efficiency, in nearly fifty towns of Great Britain, for about one-eighth of the sewage of the city of Paris, as an important part of the completed portion of the sewerage of Berlin, Stuttgart, and Brussels, and for the disposal of the whole of the sewage of Dantzic in the porous beach-sand of the shore of the Baltic Sea. In no place is there a pecuniary gain from the operation where the sanitary portion of the problem is fairly solved. The yearly deficit varies in Great Britain from a few hundred dollars, or the value of the time of the person directing it, in small towns, to several thousand dollars in the larger places. In Paris and Dantzic it has been impossible for us to get at the profit or loss of the sewage-farming, but the process taken as a whole is quite satisfactory in both those cities.

In Dantzic the contractors for the sewerage of the city were required, as part of their agreement, to dispose of the sewage by irrigation for a period of years. The sewage of Paris constituted from one-twelfth to one-fifteenth of the dry-weather flow of the Seine, being also unusually offensive and with an excessive amount of solid deposit, so that the nuisance was so great as to demand even a costly remedy.

A light loam with a subsoil of gravel is best adapted to the purpose of sewage-irrigation, and three hundred acres of it may be made to sufficiently cleanse 1,000,000 gallons of sewage daily. With that quantity, however, it would be often necessary to pour the sewage on the land when the soil was already wet enough, or even too wet, for the crops,

so that agricultural loss would be the result; and in heavy rains it would not be always possible to purify at all the sewage, which would simply flow over the land to the nearest stream.

With less than three hundred acres of land to every million gallons of sewage, any crops but grass might be almost ruined in a wet season, unless the excess of water and some of the sewage could then pass into some stream; and it must be a matter of experiment whether there would be any nuisance in case of an extremely hot day following a long-continued rain. To fully satisfy the agricultural part of the problem, one thousand acres should be provided for each one million gallons of daily sewage, although a fair result may be got with a far less area. At best, no one plot of land should be irrigated more than one day in eight in favorable weather. In time of wet soil, any crops except coarse grass, of course, would be injured by pouring additional water upon the ground; and the quantity of coarse grass that can be raised on a sewage-farm with profit is limited to the amount that may be cut and fed fresh to live stock. A dairy farm is the best use possible of sewage-irrigated land, if it be near a large city where milk finds a ready sale.

On an ordinary sewage-farm all crops may be raised. A large hotel in Paris is supplied with fruits and vegetables of the best quality from the sewage-farm at Gennevilliers, and, commonly speaking, the products of them find ready sale.

All sewage-farms that are not managed with care are nuisances. There should never be excessive nuisance; and offensive odors can be avoided in the climate of England, as they can probably also be prevented here, if sufficient land is available.

The best practicable treatment of the difficulty is upon the principle adopted for Paris; and this can be made satisfactory from all points of view, except that of profit. The plan consists in having a large tract of land upon which the sewage may be poured when that is for the advantage of the crops, and in being able to dispose in some other way of all that is not wanted on the farms.

This other way in Paris now consists in dumping it into

the river Seine. By the new plan it will be conveyed to an immense uncultivated tract of land owned by the State. Neither of these methods would be available for Worcester. We know of no other scheme so practicable as being able to provide for all the ordinary sewage by modified intermittent downward filtration, and procuring several hundred acres, upon which surface irrigation may be attempted, and extended from year to year.

Probably there is hardly another place in the State where the conditions of the problem can be so readily met as in Worcester, to remedy an evil which is fast becoming a general one in Massachusetts. Whatever may be the means adopted to purify the sewage, the first step must be to separate it from the very great, but extremely variable, amount of water uniting with it in the brook, and to provide for the direct discharge of storm-overflows into the stream, thereby involving a considerable outlay of money in so changing the present sewerage system of the city as to fulfil these requirements.

An exact comparison of the annual cost of the precipitating system and of sewage-irrigation is not practicable; the actual facts in these respects, wherever either has been adopted, having been almost always disappointing when compared with the estimates. The difficulties which must be met are new, and their cost must be decided largely by experience. Probably the annual loss by precipitation would be between ten thousand and five thousand dollars. A favorable view of irrigation in Worcester would be that, in the best years, with skilful and economical management, there might be no loss beyond the interest on the cost of the works, and that at most the deficit can hardly be over six thousand dollars a year, pumping included.

To properly dispose of the present sewage of Worcester by irrigation would require nine hundred or a thousand acres of land, which would need to be increased in the near future. Unfortunately so large an area of suitable soil conveniently located is not at command except by expensive pumping. We have therefore considered broad irrigation only in connection with modified intermittent filtration, and simply as a

possible means, to be determined by experiment, of reducing the net yearly loss to the city in disposing of its sewage by the latter process.

We therefore recommend, as the most practicable and least expensive method of disposing of the sewage of the city of Worcester, intermittent downward filtration upon so large an area (75 acres) that the sewage daily distributed per acre (40,000 gallons) will not be large enough to prevent the successful raising of crops.* Ordinary surface irrigation may be applied by private parties so far as that may be of benefit to the crops; the filtering ground, however, always being sufficient to dispose of all the sewage, whether the farmers in the vicinity choose to make use of any of it or not.

As has already been pointed out, to make the success of any method of purifying the sewage of Worcester at all probable, it will be necessary to intercept the sewage of Mill Brook Valley before it is discharged into the brook, as the natural flow of the latter is much too large to be dealt with. After careful consideration, we have concluded to recommend a separate system of sewers for the valley.

This work is incidental to all the schemes herein discussed. By it all the sewage proper of the Mill Brook Valley would be brought to Cambridge Street at the point where that street crosses the brook. At this point nearly all of the drainage of the remaining portion of the city now sewered empties into the brook, as here terminates the main sewer in Quinsigamond Avenue, which drains the Piedmont and Island Districts. In fact, it may be said that here, practically, the whole sewage of the city is concentrated. This fact determines the direction in which space must be sought for the utilization or purification of the sewage, and somewhat simplifies the problem.

A mile below Cambridge Street is that division of the city called Quinsigamond, and in Quinsigamond there is found land favorable either for intermittent filtration or for the disposal of the sludge produced by the precipitation process,

* Very extended descriptions of the various plans of disposing of the sewage of towns are given in the Fourth, Seventh, and Eighth Annual Reports of the State Board of Health, with maps of several sewage-farms, so that it will be superfluous for us to go into that matter again extensively in this.

and in the vicinity is a somewhat limited area that may be availed of for broad irrigation.

The Precipitation Scheme.

There are a number of points below Washburn & Moen's wire-works where precipitation tanks might be built; but, taking into consideration that the tanks should be remote from inhabited and growing districts, and that land favorable for the disposal of the sludge should be convenient to them, the best location appears to be at the point marked A on the accompanying map.

An outfall-sewer, three and one-half feet in diameter, with a grade of one in two thousand, capable, when running full, of conveying about 13,000,000 gallons in twenty-four hours, is to be built from Cambridge Street to the tanks on a line substantially as shown on the plan. It crosses Blackstone River in an iron pipe a little above the dam of Washburn & Moen's mills.

The main sewer of the separate system of Mill Brook Valley is to be brought to its upper end by an iron pipe under Mill Brook; and the sewer draining the Piedmont and Island Districts will be diverted directly into it, having, however, a storm-overflow into Mill Brook.

A series of settling-tanks and the necessary machinery for grinding and mixing the lime, and for handling the sludge, is to be provided at the point A. (See map.)

The approximate estimate of the cost of this scheme is as follows: —

Separate system of sewers in Mill Brook Valley	$181,500 00
Outfall-sewer, including iron pipe, etc.	62,900 00
Tanks, machinery, and buildings	55,000 00
	$299,400 00
Add 10 per cent for engineering and contingencies	29,940 00
	$329,340 00
Land and land damages	14,500 00
Total	$343,840 00

The Intermittent Filtration Scheme.

To reach the land that it is proposed to utilize for filtration, it will be necessary to pump the sewage of the Piedmont and Island Districts a height of about seven feet. The estimate therefore provides for a pumping-station at Cambridge Street with horizontal non-condensing engines and centrifugal pumps. The sewage of Mill Brook Valley can be brought to this point at an elevation that will allow it to flow into the outfall-sewer without pumping. From Cambridge Street, the outfall-sewer, 42″ in diameter, follows the same route (but at a higher grade) as in the precipitation scheme, and terminates in a small subsiding-tank, as shown at A on the plan.

The estimate covers the expenses of thoroughly sub-draining the filtration land to a depth of six feet, the cost of levelling and preparing the surface, clearing and grubbing, and of building a complete system of carriers. It is as follows: —

Separate system of sewers	$181,500 00
Pumping-station	17,500 00
Outfall-sewer, including iron pipe, etc.	55,300 00
Subsiding-tanks	9,500 00
Preparation of land for filtration	72,100 00
	$335,900 00
Add 10 per cent for engineering and contingencies	33,590 00
	$369,490 00
Land and land damages	39,000 00
Total	$408,490 00

The estimated yearly cost of pumping is $3,500.

This scheme is complete in itself, and makes ample provision for the purification of the sewage of Worcester; but should it be thought advisable to supplement it with broad irrigation, with a view to a more complete and better utilization of the sewage, the cost and preparation for irrigation should be added to the above estimate. It would require a more thorough study of the land than we have thought it necessary to bestow, to make a close approximation to this cost; but it may be stated roughly as $100,000.

(Signed) CHARLES F. FOLSOM, M.D.
JOSEPH P. DAVIS, C.E.
HENRY P. WALCOTT, M.D.

SPECIAL SANITARY APPENDIX.

II. — REPORT FROM MILLBURY.

MILLBURY, Dec. 15, 1881.

CHARLES F. DONNELLY, Esq.,
Secretary of the State Board of Health, Lunacy, and Charity.

Dear Sir, — Your communication of the 22d of July, to the selectmen of Millbury, was by them referred to the undersigned, a committee appointed by the town some years since to take into consideration and report upon the matter of the pollution of the Blackstone River by the Worcester system of sewerage. By subsequent votes of the town, this committee has been given full power to act for and represent the town in the matter. In compliance with the request (contained in your communication above referred to) "to furnish evidence of experts and others for the information of the Board," we engaged the services of George E. Waring, jun., of Newport, requesting him to investigate the matter, and furnish us with a plan, to be presented to your Board, for disposing of the sewage of the city of Worcester, so as to prevent the pollution of the Blackstone River; having in view economy in original outlay and subsequent care, effectiveness in results, and the least injury by loss of water to the industries below dependent upon the water-power of the river. The result of his investigation, and his recommendations, embodied in a paper entitled "A Project for the Purification of the Sewage of Worcester," and the accompanying plans transmitted herewith, we respectfully submit for the consideration of your Board. We understand that plans, similar to that proposed by Col. Waring, are in use at the present day at other places where it has been found necessary to prevent the pollution of rivers; and the probability of obtaining satisfactory results may be inferred from the success attained where such a plan has been adopted. Its simplicity and economy in first cost must commend themselves. In matters of detail not affecting the general plan, however, some changes easily effected may seem desirable.

Mr. Waring, although visiting the ground, used, in putting his plan upon paper, data from surveys made under the direc-

tion of your Board. It is possible that the proximity of the mouth of his proposed conduit to the village of Quinsigamond was not called to his attention. To continue the conduit further down, perhaps to the "Market land," would seem desirable in some respects. Should it be desired by your Board, Mr. Waring would be pleased to appear before you, and explain his plan in person. He has arranged, he tells us, to go South soon; and consequently such a meeting must be arranged for an early day, if at all.

In presenting the project of Mr. Waring, we wish to be understood as having no desire to oppose other plans, or to insist upon this, if others seem more promising, either in results as to purification, in pecuniary returns from the production of valuable crops by irrigation, or otherwise. To the city of Worcester a probable return from the investment is a matter of importance, and should have weight, even against a considerable increase in the first outlay. What is desired by the inhabitants of this and other towns along the Blackstone River, is relief from an evil, great at the present time, and threatening to become intolerable in the near future, as the city of Worcester increases in population. As to the means of preventing this evil we have no pride of opinion. Satisfactory results are all we ask for. Called upon by your Board to furnish expert testimony, we have employed one eminent as a sanitary engineer, and submit his recommendations, confident that they will merit the consideration of the members of your Board.

At this time, permit us to refer to a matter which we think ought not to be lost sight of in this connection. Whatever plan may eventually be adopted, there will necessarily result a greater or less loss of water; which, in the dry season of the year, when evaporation takes place rapidly, may amount to so much as to be a serious matter to the mills using the stream for water-power. Even now the loss to manufacturers is noticeable. But it is claimed that whatever water is taken for the Worcester water-supply is returned to the river through the sewers. This can, of course, be true only to a certain extent. With the sewer-water used for irrigation, and restrained for purposes of purification, the loss will be

much greater. We would urge the necessity of providing some means to make good this loss. And we respectfully ask that, should your Board report to the Legislature a plan to prevent the pollution of the river, they will also report that by means of additional storage basins, to be used for this purpose, the city should make good the consequent loss of water. For loss of water heretofore diverted from the Blackstone River, no recompense has been made by the city to mill-owners below the mouth of the sewer.

Respectfully submitted.

GEORGE A. FLAGG,
C. D. MORSE,
OSGOOD H. WATERS,
Committee of the Town of Millbury.

III. — A PROJECT FOR THE PURIFICATION OF THE SEWAGE OF WORCESTER.

PREPARED FOR THE TOWN OF MILLBURY BY
GEORGE E. WARING, JUN.

General Statement.

As I understand the problem now presented to the town of Millbury, it is to suggest some practicable plan by which the city of Worcester may withhold from the Blackstone River the waste organic matters produced by its population and its industries, and now polluting that stream. This pollution is a nuisance to the occupants of the banks of the river, and the people of Millbury are especial sufferers therefrom.

The right of riparian owners to demand that a water-course be maintained in its original state of purity will hardly be questioned; nor does the duty properly devolve upon them of pointing out the way in which matters defiling it may be diverted. This question has, in the present case, however, an especial interest for Millbury, because its best chance of speedy relief lies in the suggestion of a system of purification, which by its completeness, economy, and simplicity, will commend itself to the prudence and good sense of the offending community as promising, at an inconsiderable cost, the final settlement of a question of serious moment in its future relations with its neighbors.

In attempting to formulate such a system, I have examined carefully many of the existing purification works of England and of the continent of Europe, and have studied the recent literature of the subject. These investigations have seemed to demonstrate, that, for a city circumstanced as Worcester is, none of the so-called "chemical" processes are worth considering; that no form of profitable agricultural use, however great its promise, should now be a controlling aim; and that the main object — the purification of the foul

effluent of the sewers of Worcester — may be attained with certainty and with ease under the peculiarly favorable conditions existing.

In assigning a second place to the very important question of profitable utilization, I hasten to assert my full confidence in its complete and satisfactory solution, even where the conditions are much less favorable than here. My idea is only that it still is a question; that its solution is not yet so general and complete that an American city can be asked to accept it as final; and that the efficiency and economy of the method of purification I am about to recommend is so clearly indicated as to make the demand for its adoption in the present case, or for the adoption of its equivalent, entirely reasonable.

Although, in my opinion, the agricultural aim should not be a controlling one, it should surely be kept constantly in view, and the work should be so planned that agricultural utilization may always be easy. The proposition as it now stands relates to the cheap and efficient withholding from the Blackstone River of the foul wastes of the city, and this is all that the riparian population can exact. The further proposition of turning these wastes to profitable use concerns us all, but especially the people of Worcester, and it should claim our next consideration.

Taking the case as it stands, we find that the costly and elaborate system of sewers of Worcester includes no means for the separation of storm-water and sewage, nor is it worth while to consider such a separation at present. The main sewer has been made to include the channel of Mill Brook, — a considerable stream, which is subject to a large increase of volume during storms. The separation of the waters of this stream during dry weather is easily possible, and such separation is necessary to any economical treatment of the foul effluent. During storms, the lateral sewers being also storm-water sewers, separation is not now practicable, and the storm effluent must continue to reach the river with its burden of filth. At such times, however, the high state of dilution of the sewage, and the increased volume of the river itself, may be trusted for a long time to come to keep the

nuisance within bearable proportions. If all future sewers of Worcester are built on the principle of absolute separation, the relief may remain permanent.

Without reference to a possible future separation of storm-water and sewage in the sewers of the city itself, and accepting as sufficient the dilution of the whole effluent during storms, we must secure the most complete separation possible between the ordinary *brook* flow and the dry-weather discharge of the lateral sewers, both of which now unite to form the current of the main sewer. It has been suggested * that the main sewer be furnished with an iron pipe connected by lateral branches with the mouths of the lateral sewers, each branch being provided with an automatic gate to throw the whole flow into the main sewer itself during storms. On further consideration, it is thought that the same result might be secured by the construction of two longitudinal walls in the main sewer, — one near each side, so as to carry off the dry-weather discharge of the sewers independently, and to furnish a sufficient centre channel for the ordinary flow of the brook. The floors or inverts of the three conduits should of course be carefully formed. During storms the flow would rise above the dividing walls, and the several currents would become more or less intermingled. The outlets of the side channels should be connected with the purification works by some means which, while admitting a considerable increase of flow during the early stages of a storm, when the lateral sewers are being cleansed of their deposits, would, with the increase of the flood, be closed to even less than their ordinary capacity, — sending nearly all of the storm-flow directly to the river. This system would have the advantage of economy and simplicity, and it would secure a complete separation in the absence of storms. This is all that we can now hope to accomplish.

The dry-weather flow of the city sewers being thus separated from the waters of Mill Brook, and so brought within reasonable limits, it should, at the present outlet, be taken up by a covered conduit and carried to a point suitably dis-

* A Report upon the Possibility of utilizing the Sewage of Worcester, by Phinehas Ball, 1873.

tant. At this point it should be received in a twin chamber, either compartment of which should be large enough to cause a deposition of earthy matters only, and not large enough to allow the subsidence of any considerable amount of organic matter. For the removal of the accumulated earth the flow could be diverted from one compartment to the other.

Each chamber should be provided with two screens, one with two-inch openings to keep back coarse rubbish, and one with one-half inch openings to arrest the remaining solids. These solids should be raked out daily and composted, or otherwise treated. Experience at the screening-chambers in Berlin indicates that the quantity of these matters will be trifling.

After screening, the sewage containing its dissolved and suspended impurities undiminished, must be subjected to such treatment as will rob it of all these, and deliver it to the Blackstone River in a purified condition.

Purification Works.

The data at hand — chiefly the survey made for the Board of Health — do not furnish a sufficient basis for a precise detailed scheme. They will serve, however, for the general determination of a process which can be adapted in all its parts to the exact conditions that further surveys may establish. The following, with this reservation, is submitted as a practicable scheme for the treatment of the sewage of Worcester: —

We will assume the closed conduit to be continued for a distance of about 2,500 feet from the present outlet, mainly on the west side of the river, with a fall of 1 in 1,000. From its mouth to the beginning of the field-work (a distance of 500 feet), the conduit should be a wooden trough having a fall of 1 in 250, and wide enough to carry the ordinary flow at such a fall with a depth of less than one inch. For a further short distance the same conduit should continue on a level grade, delivering its checked flow into the main trench of the purification works.

The sewage is now cleansed of its coarser objects and of

its sand; its suspended matters have been comminuted by its rapid descent down the 500-foot incline, and it has become thoroughly aërated. It is, in short, in the best condition for the subsequent treatment proposed for it.

The land to be employed for this treatment includes all the area between the Providence and Worcester Railroad and the 412-foot contour line (about 130 acres) and two tracts of about 15 acres each lying north of this area, on the east side of the railroad; making in all about 160 acres more or less. The irregular area has been very roughly calculated; but precision is of no consequence: the amount of land is more than ample.

The method adopted combines a long, sluggish flow in ditches, between banks planted with vigorous, water-loving vegetation, and a long exposure to the air; together with a broad surface-flow over a series of extensive beds for the final purification of so much of the effluent as has not been evaporated during the long exposure over an extended surface, and by the leaves of the plants and trees grown.

In the accompanying sketch, Nos. 1 and 2 are two tracts of about 15 acres each, laid off in alternate ditches and banks, the ditches connecting alternately at each end of the field, so as to form a continuous channel from the entrance to the exit, the banks projecting between its loops from one side of the field and from the other by turns.

Except for a short distance at the beginning, where greater velocity is desirable, the ditches are 6 feet wide, and 2 feet deep from the water-line.

The banks are 10 feet wide, and 1.2 feet high from the water-line.

After making allowance for headlands, etc., each acre will give about ½ mile of ditch, or about 7½ miles for each 15-acre tract.

The sides of the banks — leaving a passage-way in the centre — may be planted either with osier-bushes or with willow-trees, or with both according to the promise of the market. Willows growing under such circumstances would produce a heavy burden of valuable pollard-lops, while the osier product would be well suited for the finer sorts of basket-

PRELIMINARY NOTE ON THE SEWAGE OF WALTHAMSTOW.

[illegible]

[illegible]

experience on the subject, that I have divided this tract into three separate areas for an alternation of use daily or weekly, or as often as may be found necessary; the interval between two uses of any one area being sufficient to secure the oxidation or destruction by vegetation of any remaining impurity of the effluent.

I am informed that it is not safe to provide for a daily production of sewage by the city of Worcester of less than 3,000,000 gallons. We may fairly assume that one-third of this will be lost by leakage and evaporation on the way, leaving 2,000,000 gallons per day to reach the swamp. This will be equal to about $\frac{15}{100}$ of a foot in depth every third day, or a total depth of about 200 inches per annum. That this is not an excessive amount of clarified and mainly purified sewage, to be delivered under such circumstances, may at least be inferred from the fact that the filtration ground at Kendal (England) has received and purified, since 1874, a depth of over 3,000 inches per annum of the very foul sewage of that town.*

Briefly stated, the process of purification here recommended is as follows: —

I. Separate the dry-weather sewage of the city and the early storm-washings of the sewers from the water of Mill Brook.

II. Allow the earthy matters of the sewage to subside.

III. Screen out the coarser objects.

IV. Expose the screened sewage in a thin sheet to the air during its rapid flow for a distance of 500 feet at a sharp fall.

V. Carry it at low velocity for about 10 miles through ditches bordered by rank-growing trees or bushes, — alternating to a second set of ditches as often as necessary, say once a week, so as to give each set a dry week for the aëration of the subsided matters.

VI. Spread the resultant effluent over 126 acres of wooded swamp land, giving each area two days out of three for aëration.

* Rogers Field, in the discussion of C. H. Bazalgette's paper on the Sewage Question.

Conclusion.

I believe that the method above described will be entirely efficient even for the treatment of more than 3,000,000 gallons of sewage per day. It will involve the minimum of cost for construction and maintenance, and will require the purchase of only about 165 acres of land of the lowest value.

It will, I think, fully and permanently meet the demands of the riparian population along the Blackstone River, and will satisfy, in the cheapest way the legal obligations of the city of Worcester.

Save for the product of the willows or other growth of the ditched and of the irrigated tracts, it makes no attempt at utilization. But this feature of the case can have only a secondary interest for the people of Millbury. How far it is right for that people to urge a more useful application of its sewage upon the city of Worcester is questionable.

At the same time it cannot be amiss to call attention to this means for securing a return for the inevitable outlay; and it is suggested that it would be a matter of small cost and of much promise for the city to secure a trial ground on the higher-lying garden or farming land near the screening chamber to which to force so much of the sewage as could with advantage be used on five or ten acres. It is more than possible — it is altogether probable — that such a demonstration of the value of sewage for agricultural use would lead to an extended demand for it during the growing season on the part of private cultivators, which would ultimately bring a good return, and would absorb a large part of the summer flow.

GEO. E. WARING, JUN.

NEWPORT, R.I., Dec. 5, 1881.

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IV. — ESTIMATE OF COST.

WORCESTER, MASS., Dec. 30, 1881.

C. D. MORSE, Esq., *Millbury, Mass.*

Dear Sir, — The following estimate is herewith submitted, of the cost of the sewage disposal works proposed by Col. George E. Waring, jun., for the diversion of the sewage of the city of Worcester from the Blackstone River: to wit, —

LAND.

30 acres purification ground, $150 per acre	$4,500 00
88 acres swamp, at $20 per acre	1,760 00
42 acres meadow, part cranberry, $100 per acre	4,200 00
Total	$10,460 00

WOODEN CONDUIT.

500 feet open wooden conduit, 20 feet wide, made of southern hard pine, floor 1½ thick and matched	$2,700 00

The foregoing estimates are taken from your letter dated Dec. 15, 1881.

2 settling-basins, 300 feet long, 30 feet wide, built in earth, with 4 screens and 5 gates	$2,900 00

CONDUIT FROM OUTLET OF SEWER TO GROUNDS.

3,000 feet brick conduit, 36 inches in diameter, trenching and brick-work, at $4.50 per foot	$13,500 00
Extra for crossing river by an iron pipe	1,000 00
Land damage	1,500 00
Total	$16,000 00

DIVIDING CONDUITS IN MILL BROOK.

From the outlet of the sewer at Quinsigamond to Cambridge Street, a distance of 4,200 feet, a 36-inch cast-iron pipe has been estimated, because the Piedmont sewer enters the main canal at the same level as the bed of the canal, and it is not practical to carry the sewage to the side of the canal.

641 tons 36-inch pipe, at $45	$28,845 00
Laying 4,200 feet pipe, at $2	8,400 00
Extra for connections	2,000 00
5,000 cubic yards concrete in 10,000 feet of Mill Brook, north of Cambridge Street, at $10 per cubic yard	50,000 00
Extra for irons and connections	3,000 00
Total	$92,245 00

ESTIMATE OF COST.

Reparation of Swamp Areas.

13,000 feet main carrier.
6,000 feet feeder to area A.
3,000 feet feeder to area B.

22,000 feet main carrier and feeder.
13,500 feet intercepting ditch to carry off surface-water.

35,500 feet ditches as above, 36,000 cubic yards' excavation, at 30 cts.	$10,800 00
6,000 feet drain ditch next railroad, at $1.25	7,500 00
4,000 feet separating dykes between swamp areas	2,000 00
48 small gates and fixtures	500 00
3 large gates and fixtures	150 00
Total	$20,950 00

Purification Areas.

Grading of 30 acres of ground preparatory for the trenching, and making 15 miles trenches, estimated to take 120,000 cubic yards of earth-work, at 35 cts.	$42,000 00
Willows	500 00

Summary.

Land	$10,460 00
Wooden conduit	2,700 00
Settling-basins	2,900 00
Brick conduit	16,000 00
Dividing conduit in Mill Brook	92,245 00
Reparation of swamp area	20,950 00
Purification area	42,000 00
Willows	500 00
Add for engineering and contingencies	18,745 00
Total estimated cost	$206,500 00

Respectfully submitted.

PHINEHAS BALL,
SIMPSON C. HEALD,
Civil Engineers.
AMOS PIKE,
Contractor.

Harvard College Library
Dec. 11, 1917.
Gift of
H. H. Carter,
of Brookline.

CITY OF BOSTON.

City Document No. 70.

REPORT ON IMPROVED SYSTEM OF SEWERAGE.

IN COMMON COUNCIL, July 12, 1877.

The Joint Special Committee which was appointed to have charge of all matters relating to an improved system of sewerage, respectfully report that the work of making the preliminary surveys is completed, and that the City Engineer has presented his report, a copy of which is herewith submitted.

As some time has elapsed since the subject of improved sewerage has been directly before the City Council, a brief recapitulation of the proceedings which led to this report may be of interest.

By orders dated February 23, and March 1, 1875, the Mayor was authorized to appoint a commission, consisting of two civil engineers of experience and one competent person skilled in the subject of sanitary science, to report upon the present sewerage of the city; the discharge of sewers into Charles river, Stony brook, South bay, or Dorchester bay; the necessity of any high-water basin on the site of the present full basin; the expediency of relieving the sewers at the South End by pumping; and to present a plan for the outlets and main lines of sewers for the future wants of the city; and to report, if it is expedient, in connection with the proposed works, to provide for any water-basin or marginal drive-ways, as ornamental and sanitary features of the city, together with an approximate estimate of the expense of any plan, or plans, for a system of sewerage submitted by them.

The Mayor appointed a commission, consisting of Messrs. E. S. Chesborough, C. E., Moses Lane, C. E , and Charles F. Folsom, M. D., who, after an exhaustive study of the

subject, submitted a report (City Document No. 3, 1876), which was referred to a joint special committee, consisting of three members of the Board of Aldermen and five members of the Common Council. This committee reported June 12, 1876 (City Document No. 66, 1876), recommending that the plan of the commissioners be adopted, and that an appropriation be made to cover the expense of the preliminary surveys. An appropriation was made and the work of making the necessary surveys was immediately commenced. It was discovered that legislative authority would be needed to authorize the construction of the system proposed, and the Legislature, at its session of 1876, passed an act empowering the City of Boston to construct the necessary works.

At the beginning of the present year the undersigned were appointed to take charge of the work of making the preliminary examinations for an improved system of sewerage, and it has been performed under their direction until the present time. The results are clearly set forth in the reports of the City Engineer and the principal assistant in charge, which are hereto appended, together with a report from Professor N. S. Shaler, who was consulted with regard to the geological questions which arose during the progress of the survey.

Your committee believe that it is unnecessary to present any argument to prove the necessity of adopting a comprehensive system of sewerage for this city. The ground has been fully covered by former reports upon the subject. In such matters great reliance must be placed upon the opinions of persons who have made sanitary science a study; and, if the mass of testimony which has been presented from time to time be reviewed, it will be seen that the evils arising from defective sewerage are descernible in this city to an alarming extent.

While it is not assumed that an improvement in the system of sewerage will secure to us complete immunity from disease, it is believed that it will remove a powerful agency for evil. Aside from questions of health, it is well known that great discomfort is occasioned to the residents of many parts of the city, who are compelled to inhale the odors occasioned by the present method of discharging our sewage. It is believed that the necessity of the improvement will be admitted, whatever differences of opinion there may be as to the proper method of relief.

The plan for an improved system of sewerage which is now presented has the endorsement of the best engineering talent in the country. It is the result of a careful study of the

different systems of sewerage now in practical operation, and an application of the best features of such systems to meet the present and future wants of Boston. It is unnecessary for your committee to attempt to explain the details of the proposed plan; for that they refer to the reports and plans of the engineers. It will be seen that the plan agrees in all its essential features with the one originally recommended by the commissioners.

Your committee have made a careful study of the scheme, and are convinced that it presents the only practicable method of effectually removing the evils which are inseparable from our present system. It appears to be the only feasible method of securing the conditions demanded of a complete system of sewerage, viz.: the immediate and uninterrupted removal of sewage from the vicinity of our dwellings to a point from whence it will not return.

Your committee would respectfully recommend the passage of the following orders.

CHOATE BURNHAM,
CHARLES W. WILDER,
LUCIUS SLADE,
EUGENE H. SAMPSON,
J. HOMER PIERCE,
MARTIN L. HAM,
GEORGE L. THORNDIKE.

The undersigned respectfully dissents from the recommendations of the majority of the Committee on Improved Sewerage.

WARREN K. BLODGETT.

Ordered, That the City Treasurer be and he hereby is authorized to borrow, under the direction of the Committee on Finance, the sum of three million seven hundred and twelve thousand seven hundred dollars; the same to constitute a special appropriation for the construction of an improved system of sewerage.

Ordered, That the Joint Special Committee on Improved Sewerage be authorized to contract on behalf of the City of Boston for the construction of an improved system of sewerage, having its pumping-station located at Old Harbor Point and its outlet at Moon Head, with all the reservoirs, pumping-works, and other appliances essential to the proper operation of said system, substantially in accordance with plans made

by Joseph P. Davis, City Engineer, and as authorized by an Act of the Legislature entitled "An Act to empower the City of Boston to lay and maintain a main sewer discharging at Moon Head in Boston harbor, and for other purposes," being Chapter 136 of the Acts of the year 1876; the expense thereof to be charged to the appropriation for Improved Sewerage.

APPENDIX.

OFFICE OF THE CITY ENGINEER, CITY HALL,
BOSTON, July 9, 1877.

ALDERMAN CHOATE BURNHAM, *Chairman Joint Special Committee on Improved Sewerage:* —

SIR, — The Joint Special Committee of last year directed me to take charge of the surveys and investigations authorized by the following order: —

"*Ordered*, That the Auditor of Accounts be, and he hereby is, authorized to transfer from the Reserved Fund the sum of forty thousand dollars, to constitute a special appropriation for the purpose of making surveys and plans and of procuring estimates for an improved system of sewerage for the City of Boston, on a line from Tremont street to Moon Island, and also on a line from said street to deep water east of Castle Island; and that said appropriation be expended under the supervision and direction of the Joint Special Committee on Improved Sewerage.

"[*Approved July* 17, 1876.]"

The investigations have now been carried so far that I am in position to recommend a definite scheme, and to give a preliminary estimate of its cost; and, understanding that it is the wish of your committee that a report should be made at once, I respectfully submit the following: —

A few days after the above order was approved, Mr. Eliot C. Clarke was appointed principal assistant, to take charge of the surveys; and his report, which accompanies this, will show what work has been done in the office and in the field. There remains for me, therefore, little else than to state what conclusions have been arrived at, and to give the estimates of cost of the various schemes that have been considered.

All the schemes are alike in their main features, and correspond with that proposed and recommended by the Commission appointed in 1875 to report upon the present sewerage of the city, and to present a plan for its improvement.

These features are: a system of intercepting sewers along the margin of the city, to receive the flow of the existing sewers; a main sewer, into which the former empty, and which, crossing the city, leads to a pumping-station; pumping machinery to raise the sewage matter some thirty feet; an outfall sewer leading from the pumps to a reservoir situated at some favorable point for dis-

charge; and a reservoir from which the sewage, accumulated during the latter part of ebb and the whole of flood tide, is to be let out into the harbor during the first two or three hours of the ebb.

In all the schemes it is assumed that at some future day a system of *high-level* intercepting sewers will be added, which will conduct to the outfall all sewage that can be delivered at the reservoir without pumping.

The Commissioners (Mr. E. S. Chesbrough, City Engineer of Chicago; Mr. Moses Lane, City Engineer of Milwaukee; and Dr. C. F. Folsom, Secretary of Massachusetts State Board of Health) state in their report (City Document No. 3, 1876) what the evils are in the existing sewerage system that require remedy, and give the reasons why a plan of the above description is recommended. While it will be needless to go over the whole ground here, it may be well to call attention to one or two of the more striking points.

In the existing system the sewage is discharged through some seventy different outlets along the shore lines of the city, and a number of these outlets may be said to be in the very heart of the city, — such as those which empty into the Roxbury Canal, South Bay, and Fort Point Channel.

As the borders of the sewered portions of Boston consist largely of broad strips of made land, filled to level planes only six or eight feet above mean high tide, the sewers are necessarily built with slight grades, and are so situated as to be tide-locked a large portion of the time. They discharge during the latter part of the ebb and the first part of the flood-tides, so that the sewage, instead of being swept out into the harbor and there diffused, is carried inland, and such portion as will deposit in still water is thrown down at the turn of the tide upon the broad areas of flats that exist within and around the city. This intermittent discharge produces other serious evils. During the time the sewage is accumulating in the sewers there is very little current in them, and, in consequence, deposits are formed which are not readily removed, and, when putrefaction begins, are the source of dangerous gases. Again, as the sewage accumulates and rises in the sewers the gases are compressed, and, since adequate ventilation is not provided, are liable to be forced through the house-drains into the houses.

The more important objects to be attained by an improved system of sewerage are, then, an uninterrupted removal of all sewage matter from the vicinity of inhabited districts, and a discharge of this matter at such a point and under such conditions that it shall not be brought back to be thrown down on our shores.

The order of the City Council refers to two points of outlet only; but after its passage other points were urged as possessing merit, and the committee thought it would be best to give them some attention, since so doing did not seem to be at variance with the spirit of the order.

Four points of discharge have therefore been considered, viz.: —

Spectacle Island.
Thompson's Island.
Castle Island.
Moon Island.

From these four points experiments with floats were made, to determine the direction and the force of the tidal currents, and to furnish a means of judging if the suspended matter of the sewage would be deposited where it would injure the ship channels or cause a nuisance.

SPECTACLE ISLAND.

The experiments show a fair current off Spectacle Island, setting out through Broad-sound channel and joining with the stronger current which passes between Castle and Governor's islands. Suspended matter, however, discharged at Spectacle Island, would be kept on the southerly edge of the channel current and would be liable (as was shown by the course taken by some of the floats) to be directed into the still water of the main ship channel between Lovell's and Gallop's Islands, where it would meet the incoming tide and be deposited.

The topography of Spectacle Island is such as to render the building of a reservoir very costly, and, although a sufficient number of borings have not been made to decide the question beyond dispute, it is probable that the island cannot be reached with an outfall sewer except at an unjustifiable expense. As a point for discharge it is evidently inferior either to Castle or Moon Island, and therefore is thrown out of further consideration.

THOMPSON'S ISLAND.

The head of Thompson's Island lies about one mile to the southwest of Spectacle, and the strongest currents passing the former also pass the latter. A float put into the current at the beginning of ebb tide, well out from the northerly shore of Thompson's, will require fully two hours to reach Spectacle, and will usually meet the incoming tide at some point near the heads of either Long or Lovell's Islands; floats put in nearer the shore will pass to the south and enter the sluggish water between Spectacle and Long islands.

The experiments show conclusively that Thompson's Island does not offer a favorable point for discharge, and hence it need not be further considered.

CASTLE ISLAND.

Castle Island is owned by the United States Government, and is the site of Fort Independence,— a fort of considerable importance on the inner lines of defence of Boston harbor.

Whether or not the city would be allowed to construct sewerage works there, or make it the point of discharge, can only be

definitely settled by petition to Congress, or application to the Secretary of War; but it seems hardly possible that any use of the island, which would in any way decrease its value as a defensive position, would be permitted; and this view has been confirmed by the best information I have been able to obtain. If it can be satisfactorily demonstrated that the discharge of sewage there would not make a nuisance, nor injure the island as a place for quartering soldiers, it is possible that permission would be granted to make it the *terminus of the outlet sewer;* but it seems almost certain that the building of a reservoir on the island itself, or on the flats surrounding it, would, to some extent, weaken its strength as a point of defence, and therefore would not be permitted.

Assuming that the reservoir cannot be built in the vicinity of the island, I have devised a scheme in which it is located on the main land at South Boston Point, and the outlet sewer is carried from there to and across the island and terminates at a point some six or seven hundred feet to the northwest of the fort.

A scheme, in which the reservoir was located on the flats to the north of the point, with a platform and pile foundation, was also considered and estimated upon, but is not here described, since such construction cannot be recommended.

The current that sets by the island is one of the strongest in the harbor, and would usually take any suspended matter, discharged into it during the first half of ebb tide, a considerable distance into Broad Sound, passing, on its way, through Broad Channel. The result of the float experiments in this current is thus described by Mr. Frank W. Ring, the assistant who had charge of the hydrographic surveys: "Floats were sent from here (Castle Island), near the wharf on the northeastern side of the island, and in vicinity of buoy No. 7. Starting at high water, the acquired distance on one tide is about 6.3 miles.

"Of the six trips from this point the average velocity per hour was 0.81 miles. The usual direction is out Broad Channel into the sound, and, upon return, the flood tide takes the floats into the bay formed by Deer Island and the reef which makes out to the southward of it; from here the following ebb takes it into the sound, to be carried to sea by the Graves, or toward Nahant.

"There is danger of material discharged at this point being carried to the main ship channel between Lovell's and Gallop's islands, where little current exists at any stage of the tide. One float out of six trips indicated this, as did also one trip from Thompson's Island.

"I would also beg leave to call your attention to the formation of the channel at this place; it being narrow and deep opposite the island, and beyond expanding and shoaler. The velocity has a tendency to decrease with the expansion, whereas for a favorable outlet the channel should concentrate its forces, increasing its velocity."

Sewage matter once carried into Broad sound would, during the turn of the tide, be held for a while in still water, allowing the heavier particles not already thrown down in the channel to deposit, and the remainder would be so diffused as to be imper-

ceptible, hence its return to the west of Deer Island could hardly produce any ill effect.

On the whole, considering simply the effect upon the harbor, Castle Island is a rather favorable point for discharge; but there are two objections of some weight to its use: one is that the sewage would there be discharged into the main ship channel through which all the vessels entering the inner harbor must pass, and the other, that, under some conditions of the current and wind, there is danger of a deposit in the important channel between Lovell's and Gallop's islands.

In reference to deposits in the channels a few words will be in place here.

The tidal currents produce a scouring effect upon the bottom of the channels, — in one direction during ebb-tide, and in the other during flood. Usually the strongest scour in the more important channels is during the ebb; hence the tendency is to gradually move all particles that can be acted upon towards the sea. Such is the effect produced in the channels opposite Castle and Moon islands. The resultant of the scour in the channel north of George's Island is only slightly seaward. In the channel between Lovell's and Gallop's islands the scouring forces are very feeble, as very little current is produced there by any movement of the tides; the resultant of these forces is inward.

The suspended matter that will be discharged in the sewage and will settle to the bottom in the channels must necessarily be of a nature to yield readily to very slight scouring forces, since the heavier particles that enter the sewers must be deposited before they reach the pumps.

While it cannot be positively asserted that no shoaling of the channels will take place in a long series of years, yet reasoning from the known facts in the case, and having regard to the experience of London, the conclusion is reached that shoaling to a serious extent will not occur.

In the Castle Island scheme the main sewer starts on Camden street, at a point near its intersection with Huntington avenue, and, following Camden street, passes under the Boston & Providence railroad to Washington street; here it turns into Northampton street and follows it to Swett street; thence passing through Swett, Preble (widened), Lowland, Ninth and N streets, it extends to the pumping-station at the corner of P and Sixth streets. The reservoir is located on a plot of ground bounded by P street, Broadway, R street, and Fifth street.

The outlet sewers are carried from here to Castle Island on a pile foundation (the whole covered with an earth embankment heavily paved and rip-rapped), and terminate in about six feet of water at low tide near the northwest shore of the island.

The estimated cost of the Castle Island scheme is as follows: —

Intercepting sewers	$623,000 00
Main sewer	648,000 00
Pumping-station, filth-hoist, force-mains, etc. .	390,000 00
Reservoir and connections	431,000 00

Wharf, sea wall, etc.	$25,000 00
Outlet sewer	410,000 00
Pier, box sewers, and connections . . .	122,000 00
Damage for displacement of tide-water . .	41,000 00
Extra for relaying existing sewers, etc. . .	100,000 00
	$2,790,000 00
Add 10 per cent. for superintendence and contingencies	279,000 00
	$3,069,000 00
Land damages	360,000 00
	$3,429,000 00

The cost of widening Preble street is not included in the estimate, as that is an improvement already contemplated and properly chargeable to another account.

The value of the real estate to be taken for the reservoir is an uncertain element. It has been set down at the valuation of the assessors for 1875.

The more important advantages of this scheme are its relative cheapness, its facility of construction in comparison with other schemes, avoiding as it does the driving of a tunnel or the sinking of a siphon; and the circumstance that it provides at once for the sewage discharged on the south side of South Boston, without requiring a special intercepting sewer for that purpose.

The chief objections to it are, the discharge of the sewage into the main ship channel, and in the vicinity of a thickly populated district, the effect that will be produced upon the value of real estate in the neighborhood of the reservoir and pumping-station, and the improbability that the United States Government will permit Castle Island to be used as a point of discharge.

MOON ISLAND.

The float experiments show a good current setting by the head of Moon Island and passing out to the Sound through Black Rock Channel.

The pole floats (which were usually about fourteen feet long and were used to obtain the mean velocity of the current) passed to the north, and the surface floats to the south, of Rainsford Island.

The northerly channel is the deeper one, and the one the strongest currents follow.

It would seem that for the first two or three hours of ebb tide, the waters of Dorchester Bay discharge chiefly through the opening between Thompson's Island and Squantum Head, thus producing a strong current close in land on the north shore of Moon Island, at just the time it is proposed to discharge the sewage. This current, passing around Moon Head, meets another from Quincy Bay, and the

CITY OF BOSTON

IMPROVED SEWERAGE

Proposed Outfall Sewer

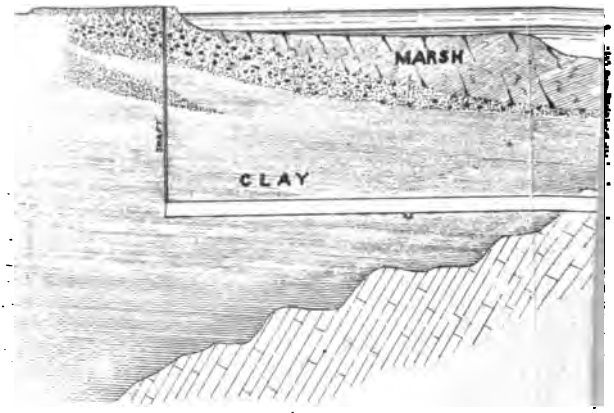
1877

HELIOTYPE PRINTING COMPANY.

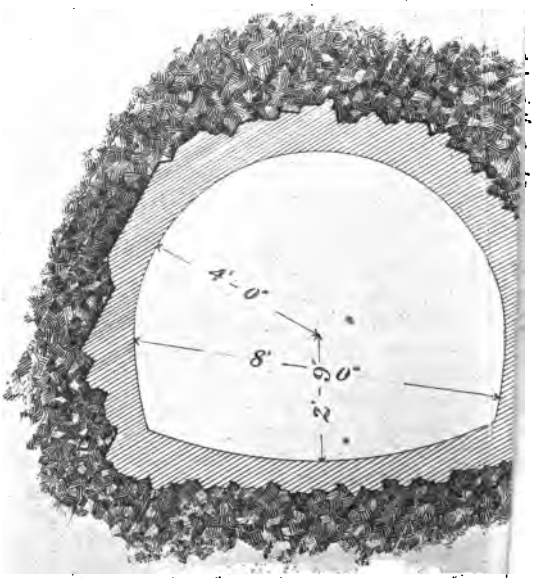
Pro

HOR. SCA

Old Harbor Point



Section in Rock



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uniting pass out through Black Rock Channel, as before described. This union of the two currents is a very favorable condition, since the inner edge of the more northerly one becomes the thread of the combined currents; and, therefore, any matter discharged off the north point of the island will follow the deepest part of the channel and meet with the highest velocities; at least, whatever the cause, floats which were started comparatively near the shore at the point where it is proposed to discharge the sewage followed the thread of the current after leaving Moon Head.

A large number of experiments were made at this place, and for a detailed statement of the conclusions drawn from them I would refer you to Mr. Clarke's report. It will be sufficient to remark here that they clearly demonstrate that Moon Island is a favorable point for discharge.

Two plans, with this island for their outlet, have been studied; one known as the Old Harbor Point scheme, the other as the Commercial Point scheme. They differ chiefly in the location of the pumping-stations and of portions of the main and outfall sewers, these differences in location causing, however, a difference in some of the details, more particularly in the method of crossing the navigable waters lying between Boston and Quincy.

The main sewer in both schemes begins on Camden street near Huntington avenue, and follows Camden and Northampton streets to Albany, from whence it will take one of two courses, to be determined hereafter, one through Swett street and the proposed East Chester Park extension, to a point about 700 feet east of the New York & New England Railroad; thence through private property to the corner of Boston and Mt. Vernon streets; the other through Hampden street, Norfolk avenue, Clapp street, and private property to the same point; thence it follows Mt. Vernon street to a point about 600 feet beyond Dorchester avenue, there turning to the right and running to a point near Crescent avenue and the Old Colony railroad. At this place the lines in the two schemes separate. In the Old Harbor Point scheme the sewer, passing under the Old Colony railroad, traverses the long stretch of marsh land known as Cow Pasture, to Old Harbor Point, where is located the pumping-station.

A good foundation in clay is found for the sewer and pumping machinery at a convenient depth under the cow-pasture marsh, and no piling will be required.

The outfall sewer leaves the point in a tunnel and passes under the navigable waters of Dorchester Bay, a distance of 7,920 feet, to Squantum Head. Here it rises to the surface, crosses Squantum Neck, and passes over the body of water between the neck and Moon Island, to the reservoir on the island. A portion of the distance after leaving the neck, where there is mud bottom, it is carried on a pile foundation, the remainder of the way on an embankment. For the whole of this distance beyond the neck it is to be covered with a heavy embankment, heavily paved and rip-rapped where necessary.

The reservoirs will discharge through capacious outlet sewers, carried well out into the tidal current.

The estimated cost of the Old Harbor Point scheme is as follows: —

Intercepting sewers	$706,000 00
Main sewer	565,000 00
Pumping-station, filth-hoist, and force-mains	390,000 00
Sea-walls, filling, shaft chamber, flushing tank, etc.	155,000 00
Outfall sewer, including tunnel	848,000 00
Reservoir and connections	431,000 00
Outlet sewer	28,000 00
Pier, box sewers, and connections	64,000 00
Dwellings for reservoir men, and other buildings	20,000 00
Extra, for relaying existing sewers, etc.	100,000 00
	$3,307,000 00
Add 10 per cent. for superintendence and contingencies	330,700 00
	$3,637,700 00
Land damages	75,000 00
	$3,712,700 00

This estimate does not include the cost of land along East Chester park extension, but does include the cost of filling 675 feet in length of that street to the full width and grade.

The more important advantages of this scheme are: —

First. A favorable point for the location of a reservoir and the discharge of sewage.

Moon Island is remote from any considerable population, present or prospective; therefore, neither the presence of the reservoir nor the discharge of sewage there can have any effect upon the value of real estate.

The sewage will enter favorable currents, which follow channels entirely outside the inner harbor.

Second. The location of the pumping-station is also remote from any lands that would be liable to be depreciated by its presence, and is such that ample room can be had at moderate cost.

Third. The lines which the main sewer follows are such as to occasion comparatively little inconvenience during construction. After leaving Albany street, if East Chester park extension is followed, but one important line of travel will be interfered with, namely, Dorchester avenue.

The chief objection to it is the siphon in tunnel under Dorchester Bay. This feature is objectionable on account of difficulty of construction, and of the special appliances to keep it from silting up. A great deal of thought has been given to the latter point, and various methods for preventing deposit, and for flushing-out deposits, when they do occur, have been considered. The method

finally adopted for purposes of the estimate is a large, covered flushing-tank at the west shaft, into which the sewage will be pumped, and afterwards let through the siphon with a velocity sufficient to prevent deposit, or to remove any that may exist. At the east end a sump is provided, into which heavy matter, if any should find entrance to the tunnel, will be swept, thence to be dredged up through the east shaft. European experience in the use of siphons for sewerage purposes may show that so much in the way of precaution is unnecessary; if so the plans can be modified.

In the Commercial Point scheme, the main sewer follows the same line as in the scheme just considered, to a point near Crescent avenue and the Old Colony Railroad; thence turning to a southwesterly course it follows the lowlands of the valley through which the Old Colony Railroad runs, crossing, just before reaching Commercial Point, about 1,600 feet of tide-water; it then passes under the railroad at Commercial street, and follows that street, or the shore parallel to it, to Union street; thence passing down Union street, it terminates at the pumping-station on Commercial Point.

From the pumping-station the outfall sewer is carried across Neponset river to Squantum; (either in the form of an elevated wrought-iron tube, supported on stone piers, with a short siphon to admit of the passage of vessels, or a submerged siphon laid the whole width of the river in the deep mud which forms the bottom at this place) thence, following Squantum Beach, and crossing Seal Bay, it reaches the line already described in the Old Harbor scheme, at a point near the east shaft of the tunnel. Beyond this point the two schemes are identical. Along Squantum Beach the sewer is carried on embankments; and across Seal Bay it is carried on piles, and covered with an embankment, protected by paving and rip-rap.

The estimated cost of the Commercial Point scheme is as follows: —

Intercepting sewers	$706,000 00
Main sewer	834,000 00
Pumping-station and filth-hoist	390,000 00
Bridge and siphon	200,000 00
Outfall sewer	1,020,000 00
Reservoir and connections	431,000 00
Outlet sewer	28,000 00
Pier, box-sewers, and connections	64,000 00
Dwellings for reservoir men, and other buildings	20,000 00
Extra for relaying or raising portions of existing sewers	100,000 00
	$3,793,000 00
Add 10 per cent. for superintendence and contingencies	379,300 00
	$4,172,300 00
Land damages	200,000 00
	$4,372,300 00

If a siphon be substituted for the bridge, the total of the estimate would be $4,160,000.

This scheme possesses the more important advantages of the Old Harbor Point scheme, and, in addition, it avoids a tunnel and reduces the siphon to a moderate length. While this is an advantage of considerable importance, it is not worth the difference in cost.

The location of the main sewer between Savin Hill and Commercial Point is a very unfavorable one, both for the building of the sewer and its maintenance.

The grade of the sewer along this stretch is from eleven to thirteen feet below low-tide, and since much the greater portion of it would be either in tide-water or along its edge the difficulties to be met in construction would necessarily be of a serious character.

IN CONCLUSION.

The objections already enumerated to the Castle Island scheme are, in my opinion, of a kind to preclude its adoption.

The difficulties to be met in the construction of the Commercial Point scheme taken in connection with the excess of cost and other matters of less importance, renders it inferior to the Old Harbor Point scheme; I would therefore recommend this latter as the best of the three, all things considered.

In Mr. Clarke's report will be found a description of the intercepting sewers and their location, with a statement of the areas drained by each and the population provided for; the data from which the sizes of the various sewers have been calculated, a description of the main and outfall sewers, also of the various sites that have been considered for pumping-stations and reservoirs, and much other information of interest in this connection.

I desire to acknowledge my indebtedness to him and his assistants for the thorough and careful manner in which they have performed the work committed to them.

Respectfully,

JOS. P. DAVIS,

City Engineer.

REPORT OF THE PRINCIPAL ASSISTANT ENGINEER IN CHARGE OF IMPROVED SEWERAGE SURVEY.

BOSTON, June 30, 1877.

MR. JOSEPH P. DAVIS, *City Engineer:* —

DEAR SIR, — I was appointed Principal Assistant Engineer in charge of Improved Sewerage Survey, on July 21, 1876. I herewith respectfully report the progress of that survey to date, with methods used and results obtained.

Although the order of July 17, in obedience to which this work was carried on, limited the survey to "A line between Tremont street and Moon Island, and also a line from said street to deep water east of Castle Island," yet, by a liberal interpretation of the order, it was assumed that any information was desired which bore upon an intercepting system of sewerage, on the general plan recommended by the commission appointed the previous year.

At the outset, several distinct, though related, subjects for investigation suggested themselves: —

First. Points of discharge; the tidal currents at such points, and their probable effect upon a body of sewage put into them.

Second. Location of the main sewer from its outlet to the city, and of the reservoir and pumping-station.

Third. Lines of the secondary intercepting sewers in the city.

Fourth. Forms and sizes of the main and secondary sewers, reservoirs, outlets, etc., and methods of construction.

Fifth. Estimates of cost of all items connected with the scheme.

HYDROGRAPHIC SURVEY.

As the position of the outlet would affect materially the whole scheme, its consideration received our earliest attention. A party for hydrographic work was organized, and began field operations July 27. This party consisted of Mr. Frank W. Ring, Hydrographic Assistant, one additional observer, two sailing-masters, and two boatmen. Their outfit included the cat-rigged boat "Fearless," and two tenders.

A projection of the harbor was first made, and the triangulation points given by the U. S. Coast Survey, together with others obtained by ourselves from these, by means of the plane table, were plotted upon it; the shore line being taken from a chart belonging to the Harbor Commissioners. A sufficient number of prominent points having been determined in this way, it was easy at any time to locate the position of a float by the sextant. At night, when

other objects could not be seen, the harbor lights furnished objects for observation.

Some difficulty was experienced in determining the best form of float. That first adopted consisted of four radiating arms, with canvas wings projecting downwards from them. [Fig. 1, Pl. 3.] Upon calm days this form indicated very fairly the surface velocity; but was too easily influenced by winds and waves to be used in windy weather, as it then invariably grounded on a lee shore.

A "surface and sub-surface" can-float [Fig. 2, Pl. 3] was used somewhat and gave better results; but the ordinary pole-float [Fig. 3, Pl. 3], about 14 feet long and 4 inches in diameter, was finally found to be the most satisfactory; indicating the mean current, which often differed both in direction and velocity from the surface current. This pole supported a flag or lantern, and, when there was danger of its grounding, a shorter one was substituted.

In all about fifty "Free-float" observations were made, from the vicinity of Moon, Castle, Thompson's, and Spectacle islands, varying in duration from 6 hours, or one ebb-tide, to 52 hours. Angles to determine the position of the float were taken each half hour, and were recorded, together with the direction and force of the wind and other data, in log-books especially prepared for the purpose.

A series of observations was also made upon eight sections, about Moon, Long, Rainsford, Thompson's, Hangman's, and Sunken islands, so that a comparative estimate might be had of the amount of water passing from Dorchester Bay to the northward or southward of Thompson's Island, and from Quincy Bay and Back Way to the northward or southward of Rainsford Island. All this work has been carefully plotted on a scale of $\frac{1}{10000}$, and is herewith submitted.

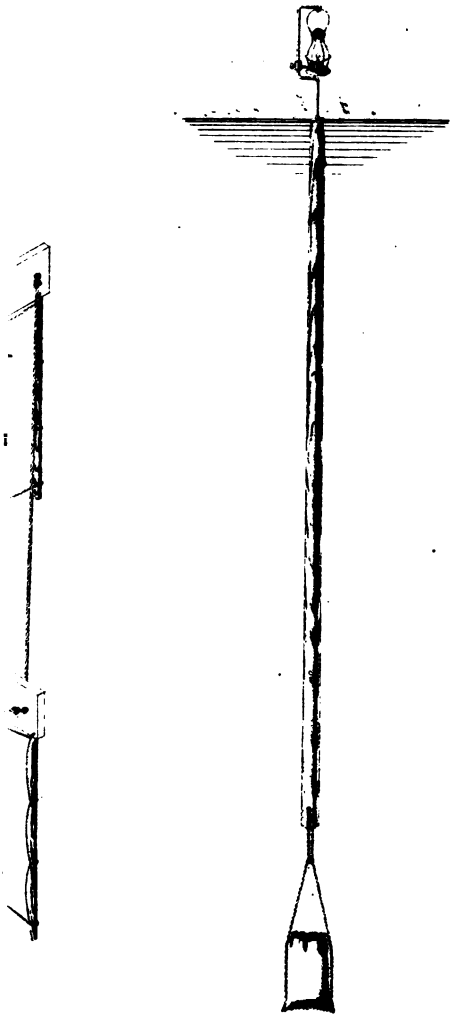
I should state that during our observations a man was stationed at a tide-gauge, and all velocities have been reduced to a mean rise and fall of ten feet.

The results deduced from our float observations may be briefly stated thus: —

Sewage discharged at Moon Island within the first three hours of ebb-tide would move seaward with an average velocity of .74 miles per hour, passing between Rainsford and Long islands, through Black-Rock Channel, and at the turn of tide would have reached a position between the Brewsters and George's Island. In its course it would be entirely outside of the inner harbor, which is assumed to be bounded by an arc of a circle, with the north part of Lower Middle Shoal for its centre, and a radius of 2.7 miles, traversing Squantum Head, Moon Head, Long and Deer islands.

Heavy matter in suspension, tending to sink at once, would be deposited in the channel of Back or Western Way, at this point 1,700 feet wide. Lighter matter in suspension would be deposited, at the turn of tide, in the vicinity of the Brewsters. Matter floating on or near the surface, in calm weather or with westerly winds, would go as far seaward as the rest, but probably in part at

Fig. 3.
POLE FLOAT.



least to the south of Rainsford Island; with a strong easterly wind it might be blown on to Moon Island or into Quincy Bay.

It is supposed that on its return with the flood tide the sewage would be so diffused as not to be perceptible. Most of it would probably return by Broad Sound to the vicinity of Deer Island, and with the next ebb would move still further seaward, not again to enter the harbor.

What would be its ultimate destiny is a matter of surmise. One hundred bottles, weighted and well corked, were put into the water at Moon Island, each containing a postal card addressed to our office, requesting the finder to mail it, stating when and where it was picked up. Of the second fifty deposited September 5, 1876, seventeen were blown upon Rainsford Island, and ten more were picked up at intervals during the next three weeks. One of these was found in the vicinity of Marshfield, about 25 miles south of its starting-point; a second at Salem, about the same distance north; and the remaining eight outside of Cape Cod, near Provincetown, Wellfleet, and Chatham, from 50 to 80 miles distant.

If the movement of these bottles may be taken as an indication of the diffusion of the sewage, it shows that in a few days it would be diluted to the point of practical annihilation, if, indeed, it were not actually destroyed by oxidation, or by being assimilated by the myriad animal organisms which pervade the sea.

Sewage discharged at Castle Island would follow Main Ship Channel and Broad Channel seaward, with an average velocity of .81 miles per hour, and would reach Broad Sound, some three miles distant from the inner harbor. A portion of it, however, might find its way into the still water between Lovell's and Gallop's islands. Its return and final exit would be similar to that of sewage discharged at Moon Island. Heavy matter would be deposited in the Main Ship Channel where it is 900 feet wide, and in close proximity to Lower Middle Shoal. Lighter suspended matter would be deposited in Broad Sound. Matter floating near the surface might be driven by an easterly wind upon Castle Island and South Boston.

Sewage discharged at Thompson's Island would divide into two parts; the lesser, skirting Spectacle Island to the north, would follow the edge of the current to Lovell's Island, three-quarters of a mile outside of the harbor. Most of it, however, would probably move slowly to the west of Spectacle Island through the Back Way, and thence to the north of Long Island, not going outside of the harbor.

Sewage discharged at Spectacle Island would follow the southerly edge of the channel, going about as far seawards as that discharged at Castle Island; but there would be more danger of a considerable portion turning into the comparatively still water of Main Ship Channel between Lovell's and Gallop's islands. Suspended matter would deposit in the ship channel and surface matter would be driven by an easterly wind into Dorchester Bay, and on to Thompson's Island.

In this connection it seems proper to consider the relative ad-

vantages which these different points offer for the location of the reservoir and outlet.

Moon Island is about 37 acres in extent. It has no present value, except as it affords poor pasturage to some cattle. A small quantity of inferior gravel has also been obtained there. A portion of the island is too high for an economical reservoir; but there are about 12 acres which would be available for that purpose, or enough for any anticipated increase in the quantity of sewage to be stored in future years. Should the advance of chemical science hereafter render it possible to obtain valuable returns from treatment of the sewage, there would be ample room for works, sufficiently remote from any habitation not to cause a nuisance.

A trial shaft was sunk 45 feet deep on the proposed site of the reservoir, and showed a gravelly soil mixed with a very hard clay; no curbing was required in sinking the shaft.

An outlet at this place presents no engineering difficulties; a good current is obtained 300 feet from the shore in five feet of water at low tide.

Thompson's Island affords a good site for a reservoir, but an expensive one. The managers of the "Farm School" established there state: "If the city should succeed in taking the island, then the managers would give up the *whole* island as unfit for the purposes of their trust; and the city would be held to supply a new site and buildings, and move the establishment to them. The rough estimate of such a substitution would be $200,000."

The outlet would have to extend into 25 feet of water to meet the current, which, as before stated, is an insufficient one.

Castle Island, 23 acres in extent, is sufficiently large; but there seems to be no reasonable hope that it could be obtained from the U. S. Government. A reservoir would, therefore, have to be constructed upon piles, between the island and South Boston, or upon the main land at City Point. Either would be expensive; the former on account of its foundation, the latter from the value of the land taken.

The outlet at this point presents no especial engineering difficulties.

A reservoir on Spectacle Island would be a very costly structure, the island being from 50 to 75 feet above low water.

The outlet would require to be constructed into about 20 feet of water.

LOCATION OF MAIN SEWER.

LAND SURVEY.

A surveying party was put into the field July 29, 1876. All islands and shores affected by the scheme were connected by triangulation, and carefully surveyed and cross-sectioned. Limits of high and low water were determined by traverse lines and ordinates. A great number of soundings were taken. Lines and levels were run, and buildings located upon all practicable routes. All of this work has been plotted on a scale of 100 feet to an inch.

ARTESIAN BORINGS.

As, whatever should be the location of the outlet, it would be necessary to cross a portion of the harbor by embankment, bridge, tunnel, or siphon, to reach main land, it was thought advisable to ascertain carefully the nature of the ground through or upon which such structures must be located. To this end, a series of artesian borings were made in various parts of the harbor. As such work requires special tools and knowledge of handling them, a contract was entered into with Mr. M. A. Lathrop, an expert in the business. He began work July 31, 1876, and completed in all 25 borings, several of them being about 100 feet deep. A 5-inch gas-pipe was driven to the full depth, and the earth excavated inside of it. This process, while it tests the ground with perfect precision, is necessarily slow and expensive. It is thought that any future experiments of this nature may be made with sufficient accuracy, and much more rapidly and cheaply, by means of smaller pipes and some of the methods of hydraulic drilling lately perfected. Careful records and samples were taken of every change of ground met with, and profiles showing developments are herewith submitted.

The results of special value obtained from this portion of our survey are information concerning deep beds of marsh mud, and strata of water-bearing gravel upon some proposed lines; and the discovery of a practicable tunnel line between Old Harbor Point and Squantum Head.

EXPERT TESTIMONY.

While making borings upon the "Tunnel Line," Mr. D. D. McBean, of Chicago, an expert miner in rock and soft ground, was engaged to examine the borings and give his opinion upon the feasibility and cost of a tunnel as proposed.

Mr. N. S. Shaler, professor of geology at Harvard University, has also examined and reported upon the geological formation about the tunnel line.

LIGHT ROD BORINGS.

The peculiar geological formation of the region about Boston, causing frequent elevations of the bed rock, not always shown by surface indications, and the sometimes unsuspected presence of deep beds of marsh mud, rendered it necessary to test carefully the nature of the ground through which it was proposed to locate the sewers, since its character would form such an important element in their cost and stability. The slowness and cost of artesian methods of boring precluded their use. Light auger rods were therefore constructed and a party organized to use them. All lines about which there was any suspicion have been tested in this way, and profiles are submitted showing the result of the examinations. 486 borings in all have been made, from ten to eighty

feet deep, averaging twenty-three feet, and at an average cost, including the price of tools, of 33 cents per foot bored.

SITE FOR PUMPING-STATION.

Four sites for the pumping-station have been examined; viz., Commercial Point, Fox Point, Old Harbor Point, and City Point.

Commercial Point presents several favorable conditions. A sufficient area could be obtained, though probably at considerable expense; the foundations would be good; the facilities for discharging coal are excellent. Although there are some dwellings in its vicinity, yet these are not very numerous nor valuable, and no large damages from any possible nuisance caused by the pumps or filth-hoist need be anticipated. To reach this point, with the contemplated "high-level sewer" would require an elevated conduit or siphon nearly a mile long.

Fox Point, the locality recommended by the commissioners, seems to be rather near the valuable residence-property of Savin Hill. It would be about as easy of access for the high-level sewage as Commercial Point. The great depth of mud at this point, between the shore and channel, would render the building of a coal wharf a difficult and costly operation. For the same reason any method of crossing the river would be so uncertain and expensive that no estimates have been made by this line.

Old Harbor Point comprises over a hundred acres, which is valued by the city assessors at about $200 an acre. It is easy of access, and its extremity is rather over a mile distant from the high land from whence high-level sewage would have to be conveyed. It is itself destitute of habitations, and sufficiently remote from any to afford assurance that operations carried on there would not be a source of offence. It would afford a good foundation for the pumps and other structures. About four acres, at its extremity, have been filled to grade fourteen, and a wharf and dock are already constructed, but would require some extension and dredging to make them accessible to coal vessels. A roadway, averaging forty feet wide, extends through the length of the point and connects it with the city streets and the Old Colony Railroad.

A pumping-station at City Point would be in the midst of a populous and valuable residence-portion of the city. The land required would be costly, and there would be considerable expense in constructing docks for coal. The foundations would be excellent. The chief objection to this locality is its proximity to what will probably be in the near future a dense population.

OUTFALL SEWERS.

The routes of the outfall sewers, as located, are shown on the accompanying plan. With the pumping-station at Commercial Point, the sewage, after crossing Neponset River by a wrought-iron siphon, or by a bridge and siphon, follows the shore of New Squantum and crosses Seal Bay on piles to Squantum Neck, which

it traverses through a rock excavation; thence again on piles across about a thousand feet of mud bottom to a sand bar, and in embankment to the reservoir at Moon Island.

From Old Harbor Point the route would be by tunnel to Squantum Neck, and thence as before to Moon Island.

From City Point the line as shown is direct to a point near the north shore of Castle Island, crossing the flats on piles.

MAIN SEWER WEST OF PUMPING-STATION.

Two elements enter largely into the selection of a route from the pumping-station at tide-water to the city proper; one is the contour of the region to be traversed, affecting the depth of cutting required; the other the character of the soil, affecting the cost of excavation and the ease of securing good foundations. A contour map has been prepared, partly from data obtained from city maps and partly from original surveys, which embraces all that portion of the city between Commercial Point, Old Harbor Point, and Tremont street.

This shows by simple inspection that the possible routes across Dorchester, by which long and expensive deep cuttings can be avoided, are limited to two or three at most. Examinations and estimates have been made of every line which seemed in the least practicable, and the ones preferred are shown on the accompanying plan.

From City Point the best line seems to be by Sixth and N streets, to Ninth street; thence by Ninth street and its extension to Lowland street; thence by Lowland street to an extension of Preble street, and by Preble street and Swett street to Albany street. It should be said that Preble street, while it is the most direct, if not the only available route by which to reach Swett street, is not, as at present laid out, sufficiently wide for our work. It has an average width of 20 feet, and a trench for constructing the 9 by 11 sewer proposed at that point will require to be 18 feet wide. There is a plan, however, for widening the street to 50 feet, by taking property on its south side, and it is assumed that this will be done; but the cost of such change has not been included in the estimate.

From Albany street westward the sewer follows Northampton street to Washington street, and then turns into Camden street, by which it crosses the Boston & Providence Railroad, and extends to a little beyond Huntington avenue. This arrangement slightly transcends the order by which it was terminated at Tremont street; but as our arrangement of secondary intercepting sewers requires one through Camden street, between Tremont street and Huntington avenue, it was thought better to extend the main that distance, it being in a direction towards its ultimate objective point at Cottage Farm station.

SECONDARY INTERCEPTING SEWERS.

The only portion of the city which it has seemed safe to leave for the present unconnected with the proposed scheme is a limited

area at the North End, comprised between Prince street on the west and Lewis wharf on the east.

The drainage from this district, it is believed, causes little, if any, offence. It is small in quantity, and discharges into deep water, with strong tidal currents.

The intercepting sewer on the west side of the city has been extended beyond the point indicated by the commissioners, so as to include the low area between Leverett and Prince streets. A few of the sewers in this region are too low to be intercepted, and will have to be rebuilt. The Canal-street sewer, for instance, is at about the level of low water, and for a long distance is lower than its outlet, being in fact but an extended cesspool. The cost of these alterations has been included in the estimates.

The course of the proposed intercepting sewers is shown upon the accompanying plan. It will be noticed that a different route has been selected from that recommended by the commissioners, by which to convey the west-side sewage to the main drain. The original recommendation was for a sewer through Park square, Eliot, and Kneeland streets, to connect with the east-side sewer at South street. It was thought that the inconvenience to trade and the public generally, which would be caused by blocking such crowded thoroughfares and interfering with the approaches to three railroads, together with the difficulty of getting under Tremont street, Washington street, and Harrison avenue, which could not be closed, made this a route to be avoided if it were possible to find another. The alternative first contemplated was a line from Marlboro' street through Parker street and the extension of Camden street. While this was under consideration, however, the city abandoned a portion of Parker street, and it is now proposed to follow Hereford street extended, across the Boston & Albany Railroad, to the street parallel to and north of Huntington avenue, and thence to the main on Camden street.

The sewage from Stony-brook area is to be intercepted by a sewer, as shown, beginning at Elmwood street; thence along the southerly side of Stony-brook culvert to Cabot street; through Cabot and Tremont streets to the main on Camden street, with a branch in Ruggles street, and two siphons under Stony-brook culvert.

The intercepting sewer for the east side of the city proper starts on Atlantic avenue at Clinton street, and, following the avenue and Federal street to Kneeland street, turns into the latter, and thence follows South and Lehigh streets to Albany street. A modification of this route, which would avoid incommoding the Old Colony freight depot, and which may, on further consideration, seem more desirable, would be to continue in Federal street nearly to the bridge, and thence pass under the Old Colony freight-yard to Lehigh street. From Lehigh street the line follows Albany street to the main at Northampton street. Should the Roxbury canal not be filled it will be necessary to pass under it by a siphon; should it be filled it may be thought preferable to follow East Chester park to Swett street.

It will be necessary to construct the Dorchester-brook sewer (now

a ditch) about a thousand feet to connect with the Moon-Island scheme, or about three thousand feet to connect with the Castle-island scheme.

The South Boston intercepting sewer is intended from the first to take all the drainage from that district which now goes into South Bay; and also that which now discharges on to the flats of Dorchester Bay. From West First street, at its intersection with Dorchester avenue, it follows Foundry street, crosses the Old Colony and New York & New England Railroads just west of the bridge on Dorchester avenue; thence in said avenue to its junction with the main at Swett street or Mt. Vernon street.

This sewer is to be large enough to take the whole drainage of South Boston, when it shall ultimately be connected. The sewage which now goes into Dorchester Bay is intercepted in the Castle Island scheme by the main itself; in the Moon-Island scheme a branch is carried from N street through Ninth, Lowland, and Preble streets.

Plans and profiles on a working scale have been made of the routes of the secondary intercepting sewers, showing all the lateral sewers and drains already built, which would be intercepted, with their sizes and grades. Data for these have been obtained through the courtesy of the City Surveyor and the Superintendent of Sewers.

SIZES AND METHODS OF CONSTRUCTION.

TERRITORY AND POPULATION.

In proportioning the sizes of our works it is necessary to fix some limit, however distant, to the territory which it is proposed to treat upon one comprehensive system. A natural limit for Boston and vicinity seems to be Charles and Neponset rivers, which, with Mother Brook connecting them, include an area of fifty-seven and eight-tenths square miles. A plan of this region has been made from data obtained from different sources, showing its principal drainage areas and contour lines for various elevations above low-water mark at Boston.

The commissioners, in their report, assume that most of the territory above grade forty can eventually be drained by a high-level intercepting sewer by gravity alone, without the need of pumping. This leaves about twelve square miles below grade forty to be drained by our present low-level intercepting scheme. Less than one-half of this is now sewered, and it will probably be long before much of the remainder will be built upon, and become tributary to the sewer. On the other hand about two square miles above grade forty is already sewered, and a larger area still will have to be cared for until the high-level sewer shall have been constructed. If, then, we take fifteen square miles, or 9,600 acres, as the area to be ultimately included in our present scheme, we shall have provided for all the territory below grade forty, and in addition three square miles, or 1,920 acres, above that grade, — an ample provision for any regions that it may be impossible to reach with the high-level sewer.

The future population upon this territory is taken at 600,000, being an average of 40,000 to each square mile, — a density nearly equal to that of the old city proper at present.

SEWAGE AND RAINFALL.

Having assumed 15 square miles and a population of 600,000 as a basis for calculation, it remains to determine the capacity required by the main intercepting sewer. Sewage proper is about identical in quantity with the water supply, which latter may be taken at ten cubic feet or seventy-five gallons per day for each inhabitant. For a maximum rate of flow it is safe to take double the average; this is in excess of English practice.

The rainfall provided for is one-fourth of an inch in twenty-four hours. This is in accordance with the recommendation of the commissioners, and common English practice in similar works. It provides in reality for a rainfall of double this amount, or one-half of an inch in twenty-four hours, as it is found that not more than half of a light rain reaches the sewers. Until the whole fifteen square miles is sewered, and the maximum of population reached, a much larger rainfall can be conveyed in the sewer. For convenience in calculation, the rainfall has been taken at $\frac{24}{100}$ of an inch in twenty-four hours instead of $\frac{25}{100}$ or one-quarter of an inch. This gives $\frac{1}{100}$ inch per hour, and $\frac{\text{No. of acres}}{100}$ = cubic feet per second, nearly.

The inclination of the main sewer is taken at one in 2,500, and of the secondary sewers, except the Stony-brook sewer, at one in 2,000. The elevation at Tremont street is five feet below low water.

The following tables show the method used in determining the sizes of these sewers: —

Territory Included between the Charles and Neponset Rivers.

DISTRICT.	TOTAL ACREAGE.			ACREAGE PROVIDED FOR.			ACREAGE SEWERED AT PRESENT.			POPULATION PROVIDED FOR.	
	Below 40.	Above 40.	Total.	Below 40.	Above 40.	Total.	Below 40.	Above 40.	Total.	Present.	Anticipated.
West side City Proper	755	65	820	755	65	820	485	65	550	64,000	93,000
East side City Proper	865	35	900	865	35	900	865	35	900	68,500	95,000
Stony-brook Area	1,220	6,280	7,500	1,220	500	1,720	400	600	1,000	18,500	80,000
Roxbury-canal Area south of Northampton st.	307	393	700	307	.....	307	120	180	300	5,000	26,000
Dorchester-brook Area	190	310	500	190	.....	190	100	100	200	2,000	13,000
Dorchester Area	1,763	2,337	4,100	1,763	.....	1,763	300	50	350	5,000	82,000
South Boston	730	170	900	730	170	900	730	170	900	58,000	100,000
Brookline	342	3,778	4,120	342	308	650	50	50	100	4,500	29,000
Brighton	1,128	1,479	2,607	1,128	372	1,500	.....	.....	.....	4,500	52,500
Newton	250	11,750	12,000	250	200	450	.....	.....	.....	1,350	15,500
Dedham	.....	421	421	.....	.....	.....	.....	.....	.....	300	.....
Watertown	50	68	118	50	50	100	.....	.....	.....	300	3,500
Waltham	50	481	531	50	50	100	.....	.....	.....	300	3,500
Hyde Park	100	1,721	1,821	100	100	200	.....	.....	.....	600	7,000
	7,750	29,288	37,038	7,750	1,850	9,600	3,050	1,250	4,300	232,550	600,000
	12 sq. miles.	45.8 sq. miles.	57.8 sq. miles.	12 sq. miles.	3 sq. miles.	15 sq. miles.	4.8 sq. miles.	1.9 sq. miles.	6.7 sq. miles.		

Main Intercepting Sewer.

SECTION.	DISTRICT DRAINED.	Acreage Provided for.			Acreage sewered.	Population.		Anticipated Max. Sewage in cub. Feet per sec.				Size of Sewer (in feet.)	Discharge running full in cub. ft. per sec. (Neville).
		Below 40.	Above 40.	Total.		Present.	Anticipated.	From Population = av. × 2.	¼" Rainfall in 24 hours.	Total.	Accumulated Sewage.		
Cottage Farm Station to Camden street	Waltham Area	50	50	100	...	300	3,500	0.81	1.00	1.81	...	...	...
	Newton Area	250	200	450	...	1,350	15,500	3.58	4.50	8.08	9.89	...	...
	Watertown Area	50	50	100	...	300	3,500	0.81	1.00	1.81	11.70	...	...
	Brighton Area	1,128	372	1,500	...	4,500	52,500	12.14	15.00	27.14	38.84	...	...
	Brookline Area	342	308	650	100	4,500	29,000	6.71	6.50	13.21	52.05	6.	70.65
Camden st. to Tremont st.	West side City Proper	755	65	820	550	64,000	93,000	21.51	8.20	29.71	81.76	7.	104.91
Tremont st. to Albany st.	Stony-brook Area	1,220	500	1,720	1,000	18,500	80,000	18.50	17.20	35.70	117.46	8.	147.28
	Hyde Park Area	100	100	200	...	600	7,000	1.62	2.00	3.62	121.08		
Albany st. to Dor. Brook	East side of City Proper	865	35	900	900	68,500	95,000	21.97	9 00	30.97	152.05	9.	199.12
	Roxbury-canal Area	307	...	307	300	5,000	26,000	6.01	3.07	9.08	161.13		
Dor. Brook to Dor. ave.	Dorchester-brook Area	190	...	190	200	2,000	13,000	3.01	1.90	4.91	166.04	9.	199.12
Dor. ave. to Cow Pasture	South Boston	730	170	900	900	58,000	100,000	23.13	9.00	32.13	198.17	9 × 11	272.12
Cow Pasture to Pumping sta.	Dorchester Area	1,763	...	1,763	350	5,000	82,000	18.97	17.63	36.60	234.77	9 × 11	272.12
		7,750	1,850	9,600	4,300	232,550	600,000	138.77	96.00	234.77	...	...	...
		12 square miles.	3 square miles.	15 square miles.	6.7 square miles.								

CONSTRUCTION OF SEWERS.

A circular form has been generally adopted for all the smaller sewers. As there will be a constant flow in them, nothing would be gained in point of friction, and something lost in strength and ease of construction, by using an egg-shape. For the purpose of our estimates, all of four feet diameter and over are assumed to be upon plank foundations, and reinforced on their sides with a backing of rubble masonry up to or above the springing line. In firm ground this would not be necessary, and something would be saved by omitting this extra masonry. All junctions are to be on easy curves tangent to the axis of the main and lateral sewers. The connections are arranged to admit only the dry-weather flow, and so much more as shall be desired. In time of heavy rain, the excess passing over a weir will continue either over or under the intercepting sewer to its former outlet.

The estimates include the cost of double tide-gates for all outlets, of the pattern now in use in the city. There are to be a sufficient number of flushing-gates at intervals in each of the secondary intercepting sewers.

The form and construction of the main and outfall sewers is best shown by reference to the accompanying plans.

Should the main sewer be located in the extension of East Chester Park it will be necessary to carry it for 450 feet over a bed of mud 100 feet deep. Here it is proposed to omit a section of masonry, and use in its stead a round wooden culvert placed on one side of the street. After the filling at this point shall have settled, and become sufficiently compacted to afford a firm foundation, which may not occur for some years, it will be possible to build the missing section without disturbing the flow. In other cases of bad foundation it is proposed to use piling to support the sewer. Where the outfall sewer is carried in embankment, it is to be tied with 2-inch round-iron rods through the arch, and with 3-inch × 1-inch bar-iron below the invert, to insure its stability. This iron will doubtless rust out in time, but not before the foundation and embankment shall have become secure.

The outfall sewer will in all cases be covered with a filling 5 feet deep over its crown and 20 feet wide on top, to weight down the arch, and to protect it from the action of frost. This embankment, when exposed to the wash of water, will be paved with stones on edge, from grade 16 to low-water mark, and below that point protected by rip-rap.

TUNNEL.

Should the Old Harbor Point line be adopted, a portion of it, 7,920 feet long, between the Point and Squantum Neck, will be in tunnel, with shafts at the pumping-station and on the westerly side of the neck.

The grade as proposed is 100 feet below low water, but under certain contingencies it may be lower. With the grade at —100, 2,120 feet in length from the west shaft will be in a stiff, plastic

clay, and the balance in rock, consisting of alternate beds of shale and conglomerate. In the clay the tunnel is to be circular, 7½ feet in internal diameter, and with walls 12 inches or 16 inches thick, as the nature of the ground may require. In rock it will have an equivalent area, but to facilitate construction will have greater breadth and a flatter invert, and will have a brick lining averaging 12 inches thick.

For a certain time after completion of the works, while only a portion of the territory and population provided for are contributing to the sewage, it is evident that the flow in the tunnel, especially the minimum dry-weather flow, will not have sufficient velocity to prevent deposits of the heavier matters in suspension. To prevent the tunnel from silting up, till such a time as the regular flow shall be sufficient to scour it, a flushing-tank is designed to be constructed at the pumping-station, high enough and of sufficient size to flush the tunnel when necessary. It will be filled by the pumps and discharged through the tunnel under a head.

At the eastern or farther shaft there will be a sump to receive deposits, and suitable arrangements for removing them.

RESERVOIR AND OUTLETS.

Five plates are herewith submitted, showing the details of construction of the reservoir and outlets. As designed, the reservoir covers an area of 235,000 square feet, and is arranged so that it may be enlarged to double its capacity when future need shall require it. It is built of stone and brick masonry, and is entirely covered with brick arches supported on piers. The floor is 9 feet above low water, surfaced with concrete, and having gutters paved with brick. It is divided into four sections, either of which may be disconnected for the purpose of cleansing. The reservoir is arranged with suitable gates and galleries, so that its contents can be discharged at any desired interval after the turn of high tide.

The whole structure is to be covered with earth filling to the depth of 3 feet. The outlets are designed to discharge under water through four openings.

The following rough approximations of the kinds and amounts of material required for the completion of the proposed works, exclusive of the pumping-station, may be of interest: —

Earth excavation	650,000	cubic yards.
Rock "	26,000	"
Earth filling	460,000	"
Brick	40,000,000	
Stone masonry	60,000	"
Concrete	23,000	"
Lumber	18,000,000	feet.
Piles	5,000	

Respectfully submitted,

ELIOT C. CLARKE,
Prin. Asst. Engineer.

A REPORT ON THE GEOLOGY OF THE DISTRICT TRAVERSED BY THE SURVEYS FOR THE TUNNEL FROM BOSTON TO MOON ISLAND.

In order to give a general basis for an understanding of the problems that present themselves in connection with the geology of this line, it will be necessary to set forth, in a brief way, the structure of the rocks lying in the basin of Boston Harbor.

The whole of the area covered by the waters of this set of harbors lying westwardly of Nahant and Nantasket Points, lies in a series of relatively soft rocks, which occupy a great synclinal or trough, that by its form has served to protect them from decay and erosion. This trough was formed between the mountain ridges, the roots of which still remaining form the ridges of the Milton and Medford hills. The beds that constitute this series of newer rocks were once much more extensive than they now are, wrapping over the hills on either side, whence decay has long since removed them.

The depth of this trough is not well known. Borings made at the Boston Gas-works seemed to indicate that in the central part of its basin its floor is at least 1,600 feet below the present surface. As is frequently the case in mountain troughs, the movements of the rocks, consequent on the formation of the furrow, has brought about a great deal of disturbance in the beds it has imprisoned. These disturbances have given rise to sundry changes, which have profoundedly affected the constitution of the beds. They have been rent by faults; breakages of an incipient character, known as joints and cleavages, have been originated in them, while the original lines of weakness derived from their bedding have been quite effaced. Dykes or fissures filled with matter intruded in a state of fusion from heat, and veins or deposits from heated waters, abound in these beds, and are to be considered consequences of the disturbances which the formation of the synclinal brought about.

The rocks which appear at the surface in this synclinal belong to several distinct groups, and represent a very considerable part of the great geological section, mechanically considered; and this is the only part of their phenomena that concerns us in this present inquiry. They are divisible into two sets: (A) The rocks having a bedded character, showing distinctly all the characteristic marks of water action operating in their formation; and (B) rocks which, having originally been stratified by water, have since been melted by fire and forced into the crevices broken in the other series, forming the masses known as dykes.

In the section it is proposed to traverse in passing along any of

the lines of survey between the neighborhood of Savin Hill and Moon Island, the rocks to be passed through of the first or distinctly stratified class are probably all within the series known as the Roxbury pudding-stone beds. This set of beds consists of a succession of conglomerates and clay-slates with a few thin bedded sandstones.

The whole formation has a thickness of several thousand feet,—probably from three to six thousand. It is nowhere shown in continuous sections, and is so broken by faults and hidden by recent deposits of gravel, clay, etc., that it is impossible to give an accurate account of the succession of its several members.

It is clear, however, that the conglomerate and shaly elements occupy about equal parts of the section, and that there are a dozen or more alternations of these materials. The conglomerates of this series are varied in their composition. The greater part of them consist of densely aggregated, closely cemented pebbles and boulders, principally of the ancient syenites, granites, felsites, and other rocks having a high degree of hardness. In these deposits generally the cementing matter binds the pebbles so strongly together that it is often difficult to separate the separate bits from the mass without fracturing them.

Their general hardness can be easily ascertained by an inspection of the quarries in the neighborhood; those at Savin Hill, on Commercial street and at other points in the Dorchester and Highland Districts, will make this clearer than it can be made by words. The clay-slates and sandstones are very much softer than the conglomerates. They are not often worked, as they yield few good quarry stones. An inspection of the quarries in North Quincy will give a good general idea of their resistance to working. At Squantum Head other forms of these shales may be conveniently seen. They all have a low degree of hardness, and may be accounted very favorable material in which to do any tunnelling work.

This point is important, inasmuch as a large part of the section between the Savin Hill shore and Squantum Neck is of this character.

The mechanical condition of these beds, impressed on them since their formation on some ancient sea floor, are substantially as follows: when the mountain downfold or trough in which these beds lie was formed, they were subjected to very great pressures consequent on the packing together of the materials into a less compass. This process has had a great variety of effects upon the rocks, of which the most important are as follows: in the first place, the beds, before horizontal, were tilted at high angles to the horizon, the average slope impressed on them being, in this district, about twenty-two degrees. This dip varies in direction, but the strike or line of no dip, drawn in the plane of the bedding, is about north 50° to 60° E. When this crumpling took place, the rocks were broken through in a great many places, and the consequent faults, varying from a few inches to several hundred feet, permitted the broken fragments to slide vertically and sometimes horizontally in relation to each other. The number of these breaks is very great. At cer-

tain points they occur every few feet in the section, but when frequent they are uniformly of small amount.

At Squantum Head, on the north-east point, these small dislocations can be readily seen, as they are well disclosed by the sea-cliff section. These breaks were always attended by the tearing of the walls sliding on each other, and when the movement amounted to more than a few feet, there was often a *breccia* or mass of angular broken fragments accumulated between the two sides of the fault. As these movements were always made under the influence of strong compressive forces, the walls of these faults are always drawn very closely together, the packing of *breccia* being often ground into powder in the process. Wherever irregularities in the neighboring walls of rock have left vacancies, the action of heated water has served to fill in the interspaces so that the faults seldom present any opening of considerable size. In perhaps a score of cases where I have been able to trace these faults for a considerable distance the actual space for the passage of water has not often exceeded the thickness of a knife-blade, and has never been continuous for considerable distances. Near the surface of the ground these beds are sometimes affected by weathering which has developed the faults into open fissures; but below the depth of say 20 feet I have never found them open in any section I have been enabled to study.

The next class of breaks to be considered are the so-called *joint planes* or breaks, which have not been attended by faulting. This class of fissures is much more important in giving the face to the rock than the fault lines. The faults are comparatively rare, not averaging one in one hundred feet over any considerable area. The joint planes are found at distances of from a few feet to a few inches. They are the product of the compression to which the rock has been subjected, and, as the compression has acted in several different directions, there are several of these joint planes inclined in various directions. Sometimes the recent shrinkage of the rocks, consequent on the continued loss of heat from the earth as well as from chemical changes, has resulted in developing these incipient fractures into slightly gaping furrows. When this occurs, which is rather seldom in this district, the opening does not generally exceed the smallest visible fraction of an inch, and is generally more of less closed in places by deposits from water. Generally the pressure which produced these joints is still so far existing that their walls are kept closely compressed.

One important effect arising from these joints is the ease with which the rock can be separated from the beds, there being no difficulty in removing masses from the layers, so distinctly are they separated by these lines of breakage. There are at least six or seven distinct joint planes in this set of beds, but only two or three are evident in any small area, and the extent to which these cut the rock is variable in different parts of any one layer. One of these sets of joint planes is particularly conspicuous: its general direction is northeast and southwest; the dip of the plane being to the north and the inclination about 23° to the horizon. This set of planes is found throughout this area, and cuts the rock so often that it gives a look of bedding well calculated to deceive the incautious eye.

The true slope of the beds is to the south by east, N. 160°; but this foliation, for such in fact it is, would be first taken by the observer for the plane of stratification. This joint plane will materially assist the work of driving a heading in the rocks between Savin Hill and Squantum.

The remaining feature which will have to be considered in our discussion of the conglomerate series is the dyke, or injected rocks that traverse it. These rocks are to be regarded as masses of lower lying stratified beds that have been melted and forced up through crevices in this superior conglomerate series. There are three points that we need to consider with regard to them, — the direction of the fissures, their width and hardness, and the closeness of the fissure or break that separates them from the country rock. There are two series of these dykes, one set lying in a meridional direction, the other running nearly east and west, generally a little north of east and south of west. The first of these series is generally rather narrow, few of them being over five to ten feet in width; those of the other series are sometimes as wide as thirty feet. There is, in Cambridge and Somerville, a class of supposed dyke materials well exposed, near the generally known "powder house" or ancient windmill, which was used for an ammunition store during the Revolution. If these deposits are really dykes, there are some of the north and south series that are over one hundred feet wide. I am satisfied, however, that these wide dykes will not be traversed by the proposed tunnel, as no trace of the material composing them is found in the drift waste south of the proposed line. The average width of the dykes of this district is not over five feet; their hardness does not exceed that of granite or the syenite of the Quincy quarries. There seems to be relatively few of these trappean rocks in this district, between the Savin Hill and the Squantum shore, if we may judge by the drift materials south of the line. If by any chance the heading should be found to run parallel with one of these dykes, it would be easy to escape from its path by a slight curve. The matter having been forced into the dyke fissures under great pressure, it greatly compressed the neighboring stratified rock and, although a certain shrinkage of the mass took place in its cooling, the elasticity of the rocks caused the walls to keep close to the contents of the chasm. Only in rare cases have I found the margin between these two rocks open enough to admit the passage of any considerable amount of water. When a cavity occurs it is generally filled with deposits laid down from heated waters. I should be surprised if a *miner's inch* of water was ever poured into the tunnel through any one of these furrows.*

There is another class of deposits in these beds which is so closely connected with the fault phenomena as scarcely to require a separate mention. I refer to the veins or fissures filled with deposits of various minerals, such as quartz and carbonate of lime. These deposits occupy shallow furrows, and are so insignificant as not to require discussion in this report. Their walls are almost

* A miner's inch of water is three thousand two hundred cubic feet in twenty-four hours, or the amount that will flow through an inch of aperture with a four-foot head.

invariably closely bound together by the vein stone. As a whole, I am satisfied that these rocks are fairly impervious to water, being as satisfactory in this respect as any that could be found along any part of our coast. They contain little interstitial water, not enough to make any trouble. The fissures are generally very narrow and at greater depths below the surface than twenty feet are apt to be reasonably tight. The materials to be traversed are decidedly less hard than those traversed in many great tunnels, that of Hoosac Mountain for instance, and are on the whole less shaken. I am inclined to believe that the overlying drift will probably prevent the entrance of water into the few fissures that will be encountered except in the cases in which it (the drift) is composed of sand, where it comes into contact with the surface of the rock. It should be said, however, that the circumstances of occurrence of these rocks are such as to make accurate and complete determinations quite impossible. In a region so profoundly disturbed by the tilting and faulting of its beds, it is impossible to make certain of the exact condition of any rocks unless they are seen. The greater part of the rock surface in this district is masked by the sea, or by the very deep deposits of drift materials. The conclusions before arrived at have a good deal of evidence in their favor, but cannot be accepted as absolute certainties.

I shall now consider the character of the tops of these bed rocks, with the object of determining the depth below the surface at which a tunnel would have to be driven in order to keep below the accidental depressions of their surface contours. I am satisfied that this is a matter of more importance than it would seem to be at first sight.

In order to understand the character of the contour of the bed rocks of this district, it will be necessary briefly to consider the conditions under which its present shape was determined.

It is one of the best-established facts in physical geology that this country has been subjected to the action of an ice-sheet, moving after the fashion of existing glaciers. To this moving ice, armed at its base with imbedded pebbles and sand, and underrun by streams of water, we owe the principal contour lines of our bed rocks. The peculiar circumstances of this wearing, done by the moving continental glacier, may be set before the reader in a brief way, taking the principal results of running water and contrasting them with the action of slow-moving ice, in order to obtain the following contrasts of conditions: —

1st. Running water at any one time cuts on a very small fraction of the surface of the district it drains; at most scarcely one hundredth part of any given drainage district is subject to its action. The ice action on the contrary involves the whole surface occupied by the glacial sheet.

2d. Running water in ordinary conditions cuts in proportion to the velocity of the movement, and not in proportion to the depth of the stream. Ice, on the other hand, does not vary in its cutting power with the rate of flow, but varies in proportion to the depth

of the ice-sheet. The deeper the sheet the greater the weight upon any given section and the stronger the erosive action.

From these differences it results that the character of surfaces made by the two actions is essentially different. A region that owes its contours to water action has, with rare exceptions, all of its slopes leading continuously downward to the sea. When, on the other hand, the contours are the product of ice action, there is absolutely no such continuity of slope. We then have all sorts of irregularities of curve, deep pools and trenches often quite without outlet, and of all sizes from a few inches to miles in diameter, marking the district worn by glacial action. Wherever the rock happened to be soft, it is burrowed out to a great depth; beside this depression, a hard mass may rise up like a steep dome, and so the wildest irregularity is produced. Generally the deeper cavities run in a northwest and southeast direction; and, inasmuch as the deeper they became the stronger the cutting action of the ice, the deep trenches are apt to be more continuous than the shallow cuts. No law of form can be traced which will enable us to determine the details of contour of a hidden surface with accuracy. It may be said, however, that at the mouth of each distinct land valley we find a very deep, wide trough continued out to sea, cutting through all obstacles, or at most leaving little save shreds of any barrier that it may meet. The other depressions away from the axes of a main valley are apt to be shorter and shallower.

With these conditions of the surface it is imperatively necessary to make a very careful reconnoissance by borings of the line to be traversed, so as to avoid the risk of encountering these irregular depressions. From a careful inspection of similar rocks when exposed in the neighborhood of the proposed work, I consider that if these soundings are made at distances of one hundred feet apart it will be necessary to allow at least fifty feet for the possible depression between these points of sounding. If the distance between the soundings is reduced to fifty feet, there should be a proportional allowance for the irregularity between them.

Even with this allowance I do not conceive that there would be perfect security against encountering deep depressions; for it is not unlikely that in the lower depths which would be attained beneath the harbor the irregularity in the cutting action may be found greater than upon the higher levels of the shore.

On top of the bed rocks we have been considering, we have another set of deposits of a much more complicated character, — namely those left by the glacial sheet, or formed from its remains by subsequent water action. In order to make their nature clear, it will be necessary to consider in brief the circumstances under which they have been laid down.

The ice-sheet in its movement over the surface, aided by the sub-glacial streams of water, cut up and mingled into the lower few hundred feet of ice a vast quantity of stones, gravel, sand, and mud. When the sheet melted this mass sank down upon the land and sea floors wherever they had been covered by the ice. We still find the remains of this deposit in the true boulder-clay, or till

such as caps the hills in Cambridge and other neighboring districts. This deposit is the oldest and least changed of all the products of the glacial period. It is a dense, impervious mass, made up of boulders, sand, and mud, rudely commingled together in an unstratified order.

As this mass sank down upon the land it was cut and swept by the streams arising from the melting of the ice, and from the action of the sea which, in the then-existing level of the shore, extended much further inland than at present.

The result is that, in the main, this mass was swept away and rearranged into more varied deposits of sand, mud, and pebbles. The only extensive deposits I have been able to find in this district lie upon the hill-tops, where they have been in a measure protected against the action of running water. The nearer we come to the sea level the less there is of this unassorted drift. I doubt if there is any of it below high-tide mark, except in the deeper pockets, such as that which lies off the mouth of the Neponset river. Wherever the currents have had access to it, we find it changed into a set of beds where the several component elements are distributed according to their sizes, — some beds being made up entirely of mud, others of sand, others of gravel of varying degrees of fineness; while at points we find beds containing little save large boulders, all the other materials having been swept away by strong currents.

These several masses of strata are not combined in any regular, well-ordered succession. There are at certain parts traces of uniformity in their relations, but the period when they were laid down was one of very great disturbances in the flow of the waters. The tidal currents and the land streams were continually changing their courses; their old channels were repeatedly filled and reopened, each change bringing additional complications to the order of the forming strata. To add to the confusion the ice, after retreating from the shore and being for a while limited to the high hills, again advanced in the shape of isolated glacial streams as far as our shore line. This movement ploughed up the previously arranged beds of sand and gravel, and required a readjustment of all their conditions near the mouths of our main rivers. The result is that no geological skill can predict the character of the beds that will be encountered in a deep excavation of any considerable length within the drift near the sea level of New England.

In this puzzling structure of our glacial deposits there are a few general statements which have a certain value as guides to our expectations. In the first place we may say that all the rearranged sands and gravels are readily permeable to water. Tunnelling in them with an open heading beneath the surface of the water is quite out of the question. The deposits holding clay are generally water-tight, or reasonably so. There is always a risk of encountering local beds of sand and gravel which have filled old channels in these clays. The position of these unseen old channels is not determinable by any means of inference.

The surface of all these glacial deposits below the water level is generally covered over by a bed of mud which has been formed since the present adjustment of the geography was effected. This deposit is somewhat impervious to water; when more than three or

four feet deep it is usually considerably consolidated by pressure and may be reckoned on as a protection against the water of the sea. The advantage which this gives is in good part counterbalanced by the fact that the land water is held beneath these muds to a greater or less extent, and as they often extend above tide mark they serve to introduce an element of pressure tending to drive the rain-water more forcibly into the submerged beds of sand and gravel.

I should say that I am inclined to believe that the deep Neponset channel will be found to contain rather more compact materials, these containing more clay, and rather more free from local sand-filled channels, than the most of our deposits of the same general nature. It should also be understood that in making soundings with the drill in this glacial drift, it is not possible to determine by a single boring the position of the bed rock. It often happens that there are many large boulders in the glacial beds, particularly near their base. The drill will thus seem to indicate bed rock when the actual position of that surface may be many feet below the place occupied by the boulder. In most cases two or three soundings should be made in order to avoid this element of risk. Yet, when even this care is taken, perfect certainty cannot be obtained, for it not infrequently happens that more than one-half of any horizontal plane will be covered by the surface of these massive boulders. Borings made with the diamond drill, by giving "cores" of the rock which the drill entered, would materially aid in this determination. In using the ordinary drill it will be better to make the three borings in one line, say ten feet apart. If they encounter rock on about the same plane it will be most likely that the bed rocks have been struck, for there are very few boulders in this country twenty feet in length. If the points where rock is struck should be in widely different horizontal planes, then it will have to be decided by other borings whether it is the bed rock or not. My experience is that large boulders are most frequently found on the convex curves of a glacial worn surface. This experience concerns points above the water level, for there have been very few sections made below tide-mark on our shores. I see no reason, however, why the conditions should be different below the surface of the present shore.

I should, therefore, advise that all the points where bed rock appears to have been struck should be carefully plotted on one diagram, and that wherever a stony ridge is shown a special study of the problem should be made by increasing the number of soundings.

Having now indicated in general terms the conditions which are likely to be encountered in the driving of the proposed tunnel, it will be well to sum up briefly the conclusions which have been forced upon me, by a careful review of all the evidence that I have been able to obtain. These conclusions are as follows, namely: —

First. That the bed rocks to be traversed by the tunnel are, as far as their hardness and general condition are concerned, on the

whole favorable to the accomplishment of the proposed work. They seem to consist of compact materials, somewhat penetrated by fissures, but not on the whole more open in texture than the Hoosac Tunnel rocks. Very many dislocations exist, and these give rise to some slightly open fissures which may afford access to the waters from above. As far as we can judge from the evidence obtained on the main land, these openings, though numerous, are not likely to be of large sectional area.

Second. That the surface of the bed rocks is certainly exceedingly irregular in outline. The ridges and, to a certain extent, the furrows of its surface are likely to be masked by heavy boulders, so that the precise condition of the undisturbed bed rock cannot be readily determined.*

Third. That the drift materials are very untrustworthy in their nature, it being impossible to determine, save by several parallel lines of soundings, exactly what beds will be passed through in making that part of the tunnel which lies within their mass.

It is my duty to say, in closing this report, that, at best, the study of the geology of this district is beset by very great difficulties.

The rocks are very much dislocated by faults, and are penetrated by a maze of intrusive dykes. The discovery of these accidents is hindered by a great coating of drift material, and is further obstructed by having the changes which a city brings to any country impressed upon the district.

The maps and photographs submitted herewith are designed to show the general condition of the district, and the circumstances under which its rocks have taken on their principal features.

Special explanations are appended to each map and plate, which will make any further description of them quite unnecessary.

(Signed) N. S. SHALER.

May, 1877.

To ELIOT C. CLARKE,
Engineer in Charge "Improved Sewerage" Survey.

* An examination of the quarry in Dorchester avenue, south of Mt. Vernon street, will show the nature of this difficulty. It will there be seen that it is almost impossible by the sounding rod to determine that the bed rock has been found.

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